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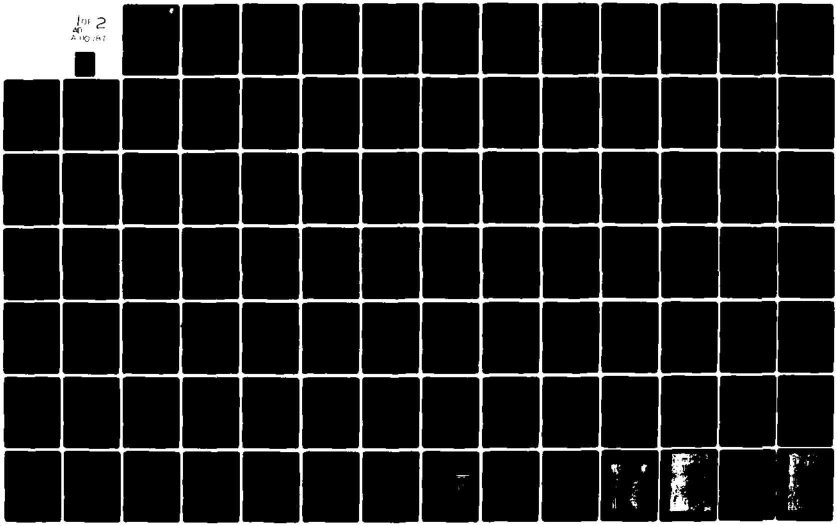

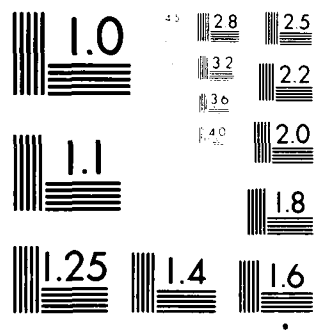

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GEOPHYSICAL AND GEOHYDROLOGIC INVESTIGATION

of

ANNISTON ARMY DEPOT

Anniston, Alabama

TECHNOS, INC.
CONSULTANTS IN APPLIED EARTH SCIENCES
MIAMI, FL 33142

SEPTEMBER 1981

FINAL REPORT

DISTRIBUTION UNLIMITED

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PREPARED FOR:

COMMANDER, ANNISTON ARMY DEPOT
ANNISTON, AL 36201

U.S. ARMY TOXIC & HAZARDOUS MATERIALS AGENCY
ABERDEEN PROVING GROUND, MD 21010

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Surface remote sensing techniques along with geohydrologic investigations were employed at Anniston Army Depot, Calhoun County, Alabama to evaluate the potential of groundwater contamination and its subsequent migration and movement into and within the bedrock. These techniques were successfully used to delineate the horizontal and vertical boundaries

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of seven buried chemical sludge trenches. In addition conductive plumes, as determined by electromagnetic and resistivity techniques, were delineated at several locations throughout the area of investigation. Groundwater flow directions were established and were found to be highly dependent upon the local topography. The regional groundwater flow is in a south to southeast direction. In general, the regional bedrock throughout the study area is a planar surface dipping gently to the south-southeast with the depth to bedrock varying locally from 20 to 100 feet. Based upon the thickness of overburden and soil permiabilities the probability exists that a contaminant from AAD activities has reached the bedrock surface. A sinkhole in the northern part of the study area appears to fall on a lineation formed by sinkhole features relating to a possible fracture. Evidence of possible fracturing or faulting associated with the Jacksonville fault was identified in the southeast part of the study area.

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Note: BP denotes Back Pocket of report

INTRODUCTION

Storage or disposal of chemical wastes pose a potential hazard to the groundwater environment at Anniston Army Depot (AAD). The Depot, situated approximately ten miles west of the city of Anniston, Alabama, in Southwest Calhoun County, performs various activities including military vehicle and equipment repair, overhaul and modification.

TECHNOS,INC was contracted by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) to assess the impact of these activities upon the ground water quality. This evaluation, performed over a 1.6 square mile area, involved geohydrologic investigations along with a remote sensing survey integrating various geophysical methods.

TECHNOS employed the above techniques to:

1. Delineate the horizontal and vertical boundaries of buried chemical sludge trenches.
2. Determine the presence and location of contaminant plumes with emphasis on the area around the buried chemical sludge trenches.
3. Determine the direction of groundwater flow.
4. Determine the depth to bedrock with emphasis on the area around the buried chemical sludge trenches.
5. Evaluate the potential for movement of contaminants into and within the bedrock.

SUMMARY AND CONCLUSIONS

The following significant information and conclusions were derived from the results of the investigation conducted at the Anniston Army Depot:

1. Six buried trenches and the buried portion of a seventh operational trench were delineated.
2. Shallow conductive plumes were found at the following sites:

   Chemical sludge trenches

   Sanitary landfill

   Abrasive dust disposal area

   Southwest corner of chert road loop

   Old lagoon

   New lagoon

   Area northeast of old lagoon and south of test track.
3. Based upon shallow EM data, contaminant plumes in the southern part of the site were mapped to the edge of Dry Creek (southeast boundary of the AAD); no data were collected off the depot.
4. Plume directions vary from site to site as a result of the local groundwater gradient.
5. All results indicate that the shallow groundwater gradient generally follows the topography.
6. Groundwater flow is generally in a south to southeast direction.
7. Plume directions derived from EM conductivity measurements and the groundwater flow based upon water level measurements are in agree-

ment. This provided a higher level of confidence in assessing the groundwater flow direction.

8. The contaminant plumes and groundwater gradients were derived from near surface measurements. Groundwater flow at depth cannot necessarily be infered from these results.

9. Interpretation of water level data was limited to ±2.5 feet due to:

   a) a sampling program being conducted by AAD personnel. This resulted in variable recovery rates of sampled wells caused by differences in permeabilities, well casing size and screen areas.

   b) broken well casings affecting elevation measurements.

   c) uncapped wells permitting entry of rainwater.

   d) wells not drilled sufficiently deep into the water table (dry wells).

   e) possible influence of variable well depths below water table.

   f) variables in well construction.

10. Regional bedrock throughout the study area can best be described as a planar surface dipping gently to the south-southeast; local variations in bedrock elevation are vaguely expressed in topographic relief.

11. Localized areas of the bedrock surface were found to be highly irregular.

12. Based upon geologic and geophysical investigations and a review of the literature, the limestone underlying the AAD is susceptible to fractures and solution cavities.

13. Given documented soil permeabilities, thickness of overburden and duration of burial, it is possible that contaminants have reached

the bedrock.

14. The bedrock underlying and adjacent to the extreme southeast corner of the AAD is complicated by various lithologies and the occurrence of a fault.

RECOMMENDATIONS

1. In the event the chemical sludge trenches are excavated and disposed of in a secure site, the saturated bermed material between the trenches should also be removed.
2. Several wells that penetrate into the bedrock should be installed. The wells should be regularly spaced in a network design to provide coverage over the entire 640 acre study area. These wells will provide detailed geohydrologic information to help evaluate the potential entry of contaminants into bedrock as well as provide information on the deeper groundwater regime (at present, such information is not available). The following methods should be used during these operations:
   a) Geologic logging of drillholes.
   b) Semi-quantitative in-field analyses of soil and water samples (i.e., portable vapor analyzer/gas chromatograph).
   c) Head tests to determine permeability at different depths.
   d) Geophysical logging of drillholes including:
      - o Spontaneous potential - bed thickness, permeable rocks, geologc correlation.
      - o Resistivity - effective porosity or true resistivity.
      - o Caliper - fractures and solution openings within limestone.
      - o Natural Gamma - clay or shale content, lithology, stratigraphic correlation.
      - o Neutron - moisture content above water table, porosity below water table.

o Gamma-gamma - bulk density or porosity.

e) Wells finished with multiple piezometers at three depths (determined from geologic and geophysical logs) including one in the rock at the bottom of the hole. The piezometer data would be used to determine areas of recharge, discharge or lateral flow. (It should be noted that the shallow ground water table gradients reported in this report do not necessarily represent the flow regime at depth.)

3. Additional shallow monitor wells should be installed in the following areas (See Plate 2):

   a) adjacent to northeast corner of the new lagoon

   b) area immediately south of test track

   c) industrial area between Dry Creek and N-S drainage channel

   These wells should be placed within the coincident EM anomalies in these areas. The logging and sampling methods outlined in Recommendation #2 are also applicable with these well installations.

4. In order to acquire an understanding of the three-dimensional aspect of the contaminant plumes, deeper EM surveys (to 45 and 90 foot depths) should be conducted. These EM results may be used to minimize drilling costs.

5. Additional shallow and deep EM profiles and resistivity soundings should be conducted outside the depot boundary to determine the extent of contaminant plume migration.

6. An extensive geologic investigation adjacent to the southeast corner of AAD would better define the location and extent of the Jacksonville fault and its possible hydraulic connection with Coldwater Spring. A review of any additional USGS or Alabama State data pertaining to the local geology and hydrology of the site would be appropriate.

7. Resolve discrepancies in surveyed well elevations to determine if risers have been broken off or added on since the original ESE survey was performed.

SITE SETTING

Anniston Army Depot (AAD) is situated in northeast Alabama in the southwest corner of Calhoun County (Figure 1). The depot consists of 15,214 acres located approximately ten miles west of Anniston, Alabama. This investigation was focused on 640 acres in the southeast corner of AAD (Figure 2).

CLIMATE

Calhoun County has a moist, temperate climate with a mean annual rainfall of 52.2 inches. Rainfall is fairly uniform during the nine month rainy season from December to August, with March being the rainiest month averaging 6 inches. The driest month is October having a monthly average of 2.7 inches. Mean maximum temperatures are 58 degrees F. and 90 degrees F. for January and July, respectively with an annual mean of 62.5 degrees F. (Warman and Causey, 1962).

PHYSIOGRAPHY

Calhoun County is almost entirely within the Valley and Ridge province of the Appalachian Highlands except for a small area in the eastern part of the county that extends into the Ashland Plateau district of the Piedmont Upland (Warman and Causey, 1962). The topography is flat to gently rolling in the western part of the county. It is mountainous in the eastern part where elevations reach 2,100 feet above sea level along the crest of Choccolocco Mountain. Elevations in the immediate survey area range from 620 to 800 feet.

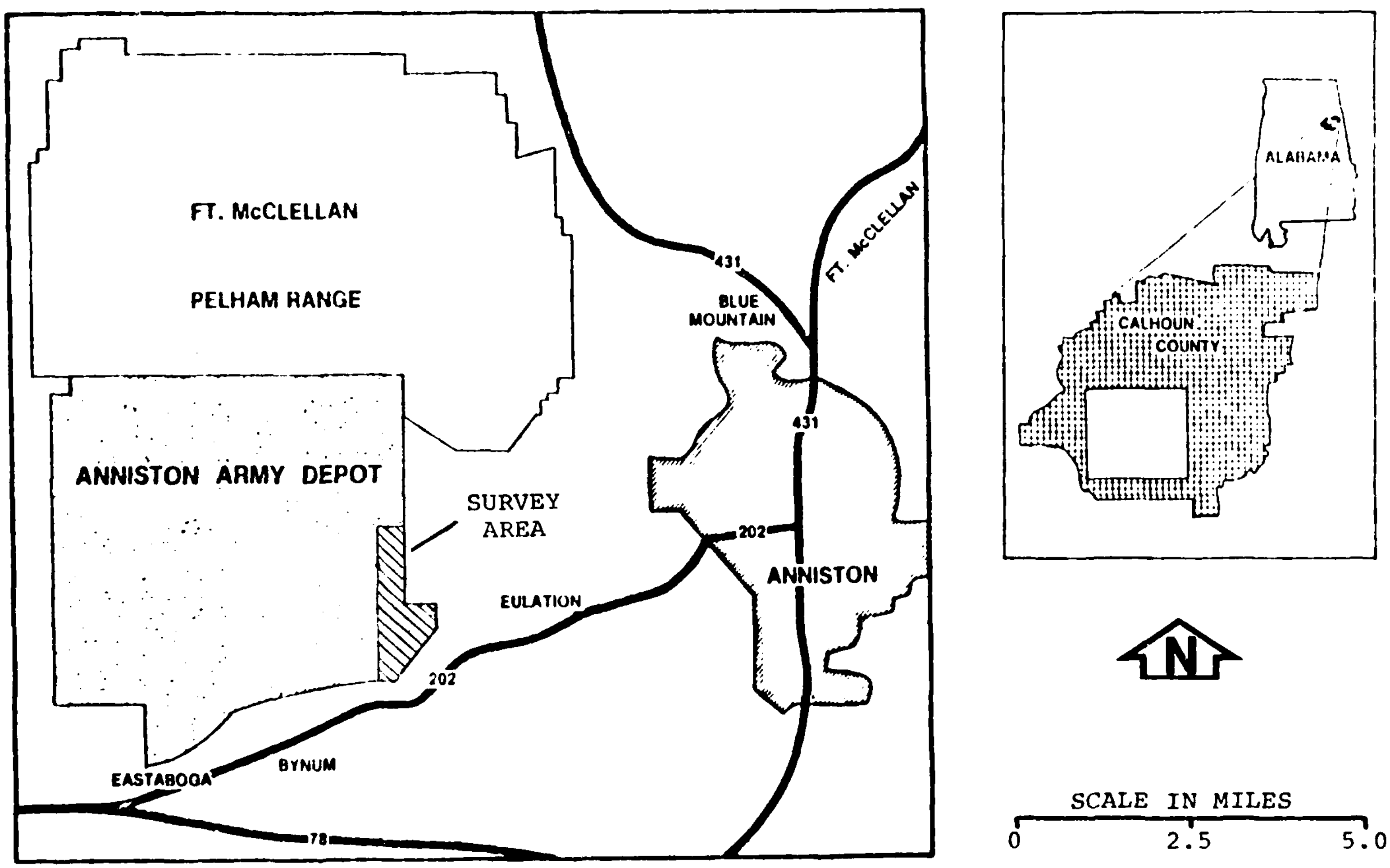


FIGURE 1. General area location map.

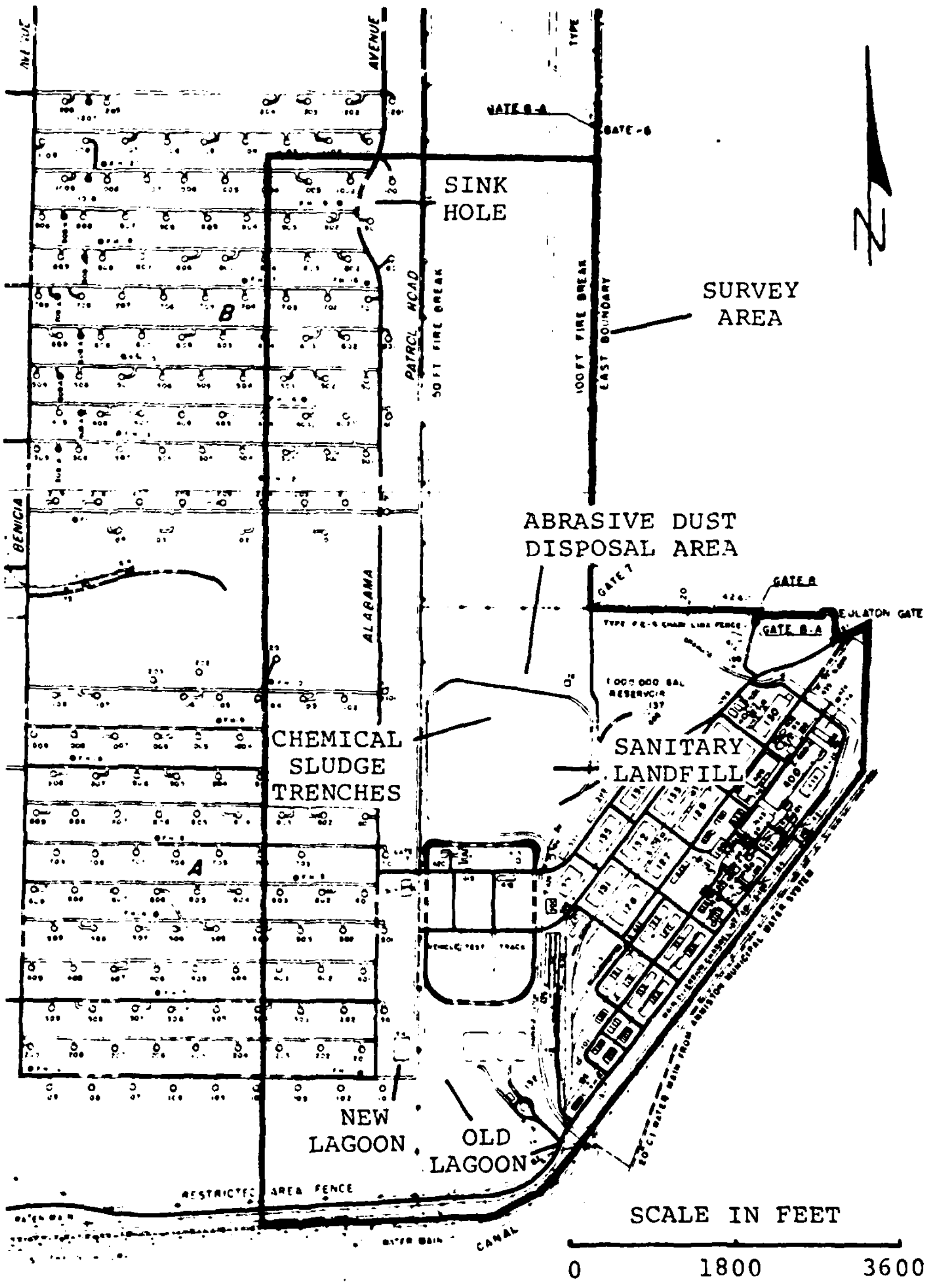


FIGURE 2. Specific site location map.

The Valley and Ridge Province in Alabama is characterized by northeastward striking valleys and ridges developed in highly folded and faulted sediments of Paleozoic age. AAD lies predominantly in the Coosa Valley which is bounded on the southeast by the Weisner Ridges. The Weisner Ridges are a series of maturely dissected monoclinal mountains of strong relief, developed upon the resistant Weisner Quartzite (Johnston, 1933). The Coosa Valley district extends for 100 miles northeast and southwest with a maximum width of 20 miles. Johnston (1933) reports that the greater part of this valley may be characterized as a mature plain with structural ridges of low relief.

A drainage divide bisects AAD from the east-central boundary to the southwest boundary. The entire 640 acre area of this survey lies south of this drainage divide. All of the surface water in this 640 acre area drains southeast to Dry Creek, the principal drainageway in AAD, which then flows south to Choccolocco Creek.

SOILS

Warman and Causey (1962) report that unconsolidated deposits extend over large areas of Calhoun County. Alluvium, colluvium and undifferentiated cover are particularlly well developed in the Anniston area. The alluvium consists of sand, silt and clay; the colluvium is similar but includes larger rock fragments up to boulder size. The permeabilities of the soils (undisturbed Shelby tube samples) in the survey area range between 2×10^{-7} to 7.2×10^{-5} cm/sec (ESE, 1981).

STRATIGRAPHY

The stratigraphic and structural relationships of the rocks through-

out most of Calhoun County are typical of the Valley and Ridge province of the southern Appalachian Highland (Warman and Causey, 1962). Consolidated sedimentary rocks consisting of limestone, dolomite, sandstone, shale and quartzite range in age from Cambrian to Pennsylvanian. Along the eastern edge of the county, metamorphic rocks have been thrust northwestward and overlie rocks of Cambrian and Ordovician age.

The formations of concern in this survey area are the Weisner Quartzite which is capped by the Shady Dolomite followed in turn by the Rome Formation and the Conasauga Formation, all of Cambrian age. Resting upon the Conasauga Formation are the differentiated limestones (Ketona Dolomite, Copper Ridge Dolomite and Chepultepec Dolomite) of Ordovician and Cambrian age. Figure 3 shows the bedrock geology in the AAD area. In Figure 4 a generalized geologic cross-section is illustrated.

HYDROLOGY

Warman and Causey (1962) report that rain is the source of most ground water in Calhoun County. Rainwater which is not evaporated or transpired, percolates downward to the saturated zone and becomes ground water. Because of their low permeability, the unconsolidated sediments overlying the rocks in the area are generally poor aquifers.

Although the consolidated rock units in the area have little primary porosity, the occurrence of cavities, fractures and faults makes possible the movement of ground water. Coldwater Spring, the main water source for the city of Anniston and the largest spring in the Valley and Ridge province in Alabama (32 million gallons per day), flows from fractures within the Weisner quartzite (Johnston, 1933). Coldwater Spring is approximately one and one half miles south of AAD. The other limestone and

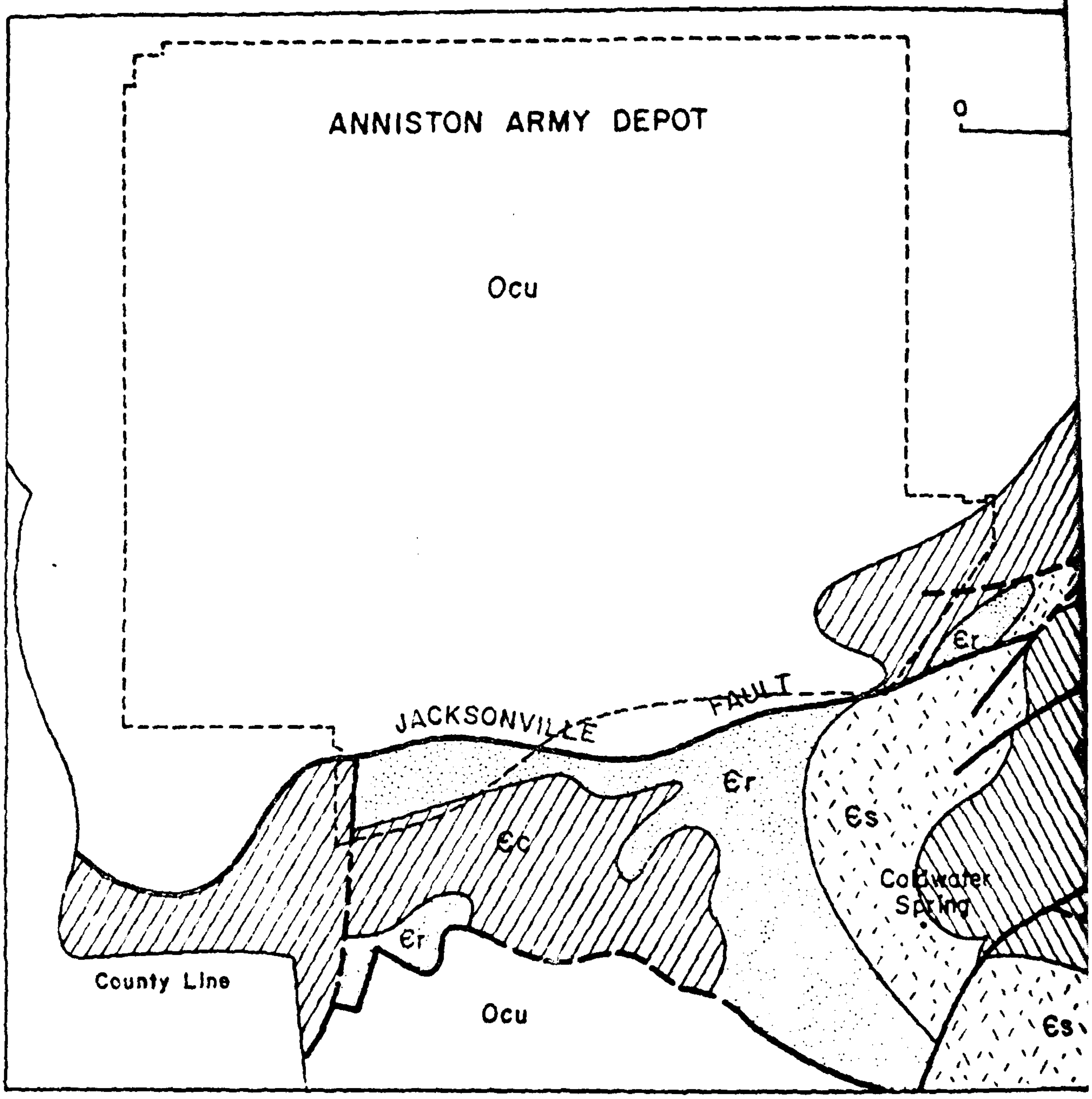
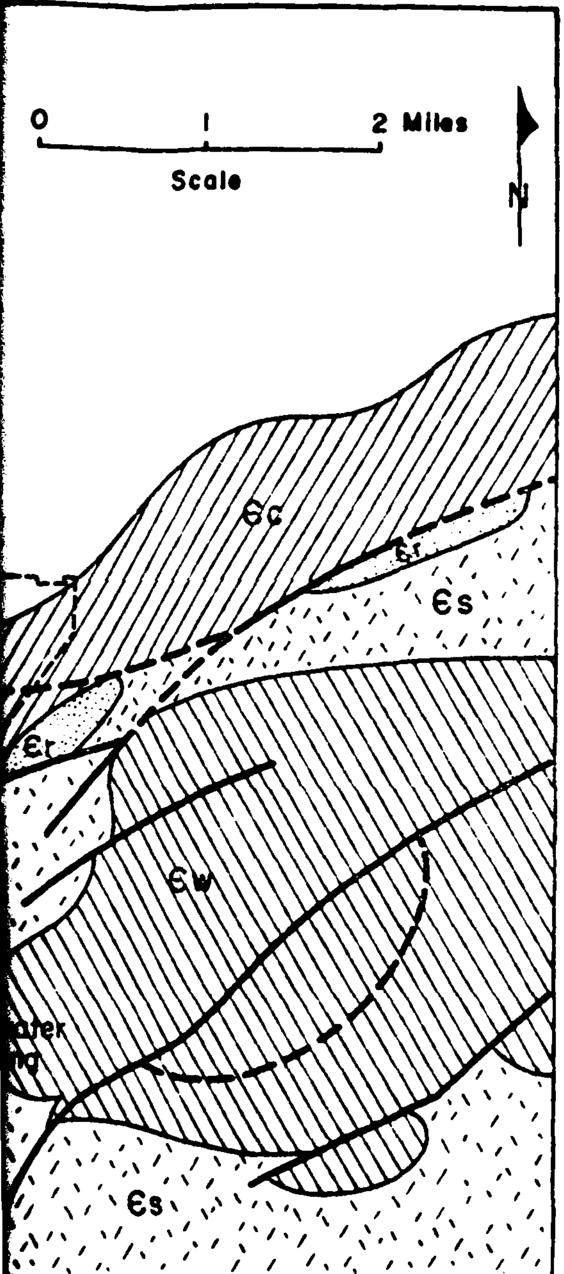


FIGURE 3. Geology map of AAD area. Taken from Warman and Cau



SYSTEM	STRATIGRAPHIC UNIT	SYMBOL	ROCK CHARACTER
Ordivician and Cambrian	Chepultepec Copper Ridge and Ketona, Undifferentiated Dolomites	Ocu	Dolomites, siliceous; abundant chert except in the Ketona.
Cambrian	Conasauga Formation	Єc	Limestone, dolomitic limestone, and dolomite, gray, crystalline; minor gray shale which weathers green. Shale becomes dominant to the north and northwest.
	Rome Formation	Єr	Shale and siltstone, red; green shale and red and light-gray sandstone; locally includes lenticular beds of light-gray limestone or dolomite.
	Shady Dolomite	Єs	Limestone and dolomite, yellowish to light- to dark-gray, crystalline, medium- to thick-bedded; variegated clayey shales in lower part.
	Weisner Formation	Єw	Shale, siltstone, sandstone, quartzite and conglomerate. Forms mountains. Local deposits of limonite, manganese wad, bauxite, and hematite.

FAULTS

Observed

Inferred

an and Causey (1962) geologic map of Calhoun County, Ala.

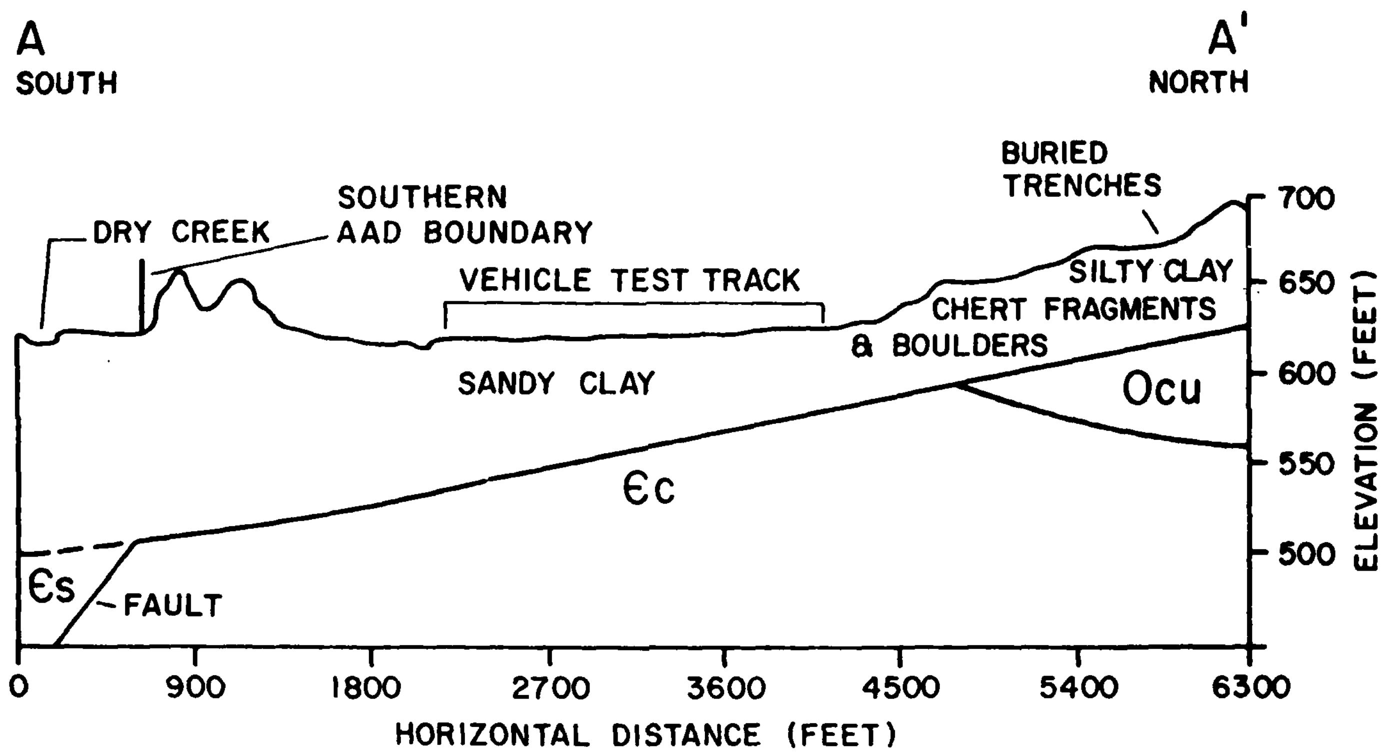


FIGURE 4. Generalized geologic cross-section of survey area. The bedrock units are the Shady dolomite (Єs), Conasauga formation (Єc) and Ordovician/Cambrian undifferentiated dolomites (Ocu). The bedrock data was taken from Warman and Causey (1962). See Figure 8 for cross-section location.

dolomite rock units in the area are generally good aquifers yielding abundant water to dug and drilled wells as well as having numerous springs.

Based upon water table measurements, the general movement of groundwater in Calhoun County is to the south and west. In the eastern part of the county the flow follows the trend of the topography (Warman and Causey, 1962). The location of AAD in relation to the county is shown in Figure 1.

INVESTIGATION OF TRENCH LOCATIONS

OBJECTIVE

Since 1971-72, several trenches located northwest of the industrial area (see Figure 2) have been evacuated and used to dispose of uncontained as well as drummed sludge from paints containing chromium, lead and zinc. Other chemical sludges, including vapor degreaser possibly containing trichlorethylene and paint/metals were also disposed of in this area. As the trenches became full, they were subsequently buried. The objective of this phase of the geophysical effort was to delineate the horizontal and, to some extent, vertical boundaries of these covered waste disposal trenches. Once the horizontal boundaries were determined, they were marked with metal stakes which were then surveyed.

SUMMARY

A total of six buried trenches and the buried portion of an existing seventh trench were located using geophysical methods. Their boundaries were marked with metal stakes at the four corners of each trench (Figure 5). The surveyed coordinates for these stakes are presented in Table 1.

The approximate dimensions of the trenches shown and numbered in Figure 5 are as follows:

1) 250 feet by 25 feet 10-12 feet deep
2) 250 feet by 20 feet 10-12 feet deep
3) 100 feet by 15 feet 10-12 feet deep
4) 100 feet by 30 feet 10-12 feet deep
5) 200 feet by 15 feet 10-12 feet deep

TABULAR DATA REPORT

(TRENCHES)

1

Northing	Easting
1142613.426	470924.4122
1142633.573	470940.0439
1142724.736	470716.2996
1142742.900	470733.3492

2

Northing	Easting
1142593.021	470942.0937
1142577.909	470938.3383
1142688.536	470720.3460
1142711.775	470729.9136

3

Northing	Easting
1142572.008	470867.3493
1142584.482	470900.1623
1142624.416	470790.4623
1142638.030	470797.7192

4

Northing	Easting
1142545.147	470856.2758
1142563.439	470885.9534
1142590.003	470777.4141
1142613.636	470791.2324

5

Northing	Easting
1142498.787	470900.7267
1142513.230	470920.0506
1142592.574	470712.1138
1142600.842	470722.1232

6

Northing	Easting
1142454.092	470880.2540
1142484.383	470893.1767
1142580.329	470662.6300
1142606.652	470670.2024

7

Northing	Easting
1142388.166	470913.1707
1142413.979	470936.1208
1142527.236	470648.9829
1142553.863	470664.5510

TABLE 1. Coordinates of corner stakes locating trenches.

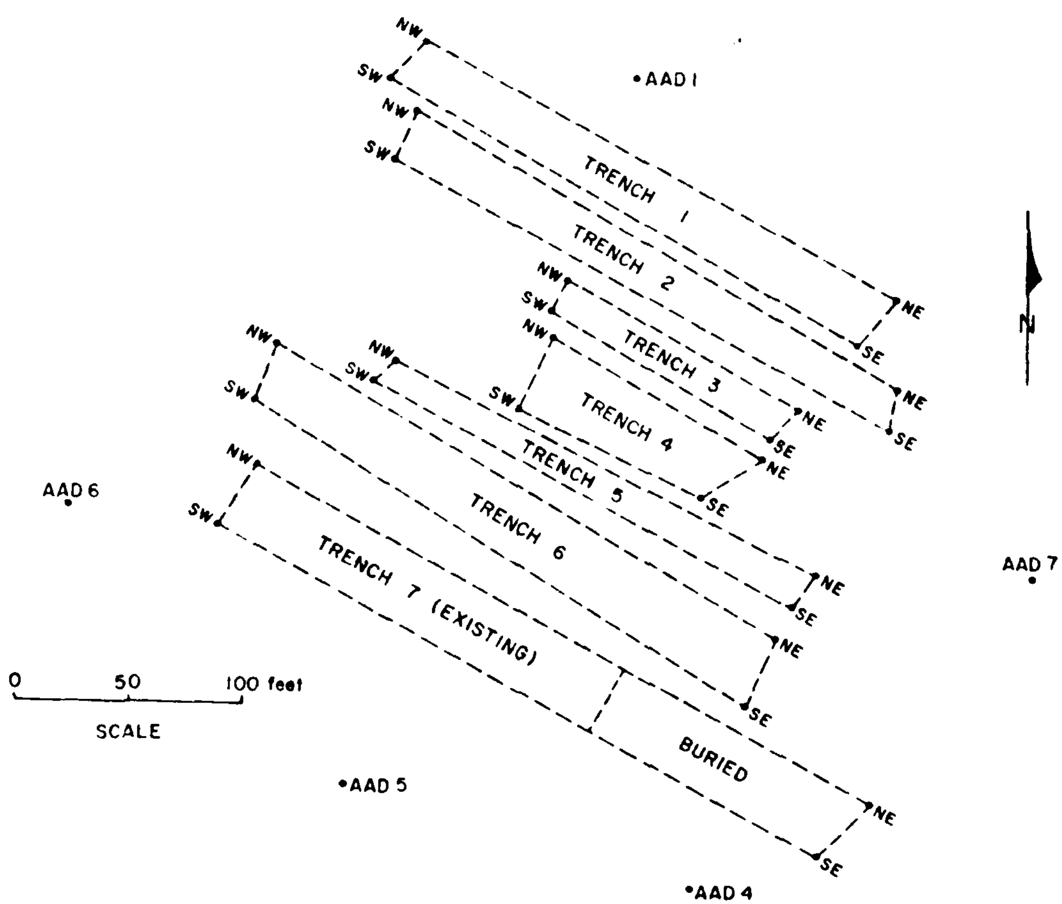


FIGURE 5. Location map of buried chemical sludge trenches. See Table 1 for coordinates of corner stakes.

6) 250 feet by 30 feet   10-12 feet deep

7) 300 feet by 30 feet   15-17 feet deep (existing trench)

FIELD PROCEDURES AND METHODS

Prior to beginning the geophysical survey, the area north of the existing chemical sludge trench was surveyed and gridded using yellow marking flags. The grid was set up using 25 foot spacings in a north-south/east-west coordinate system. A barbed wire fence along the Chert Road to the north of the site was used as the north-south zero reference line. The east-west zero reference line was perpendicular to the fence and adjacent to the western berm of the existing trench. This grid provided a total of 15 parallel lines, 350 feet long, along which the geophysical surveys were conducted in a north-south direction approximately perpendicular to the trench axis.

The geophysical methods used in the trench investigation included: Magnetometry (MAG), Metal Detection (MD), Electromagnetics (EM), and Ground Penetrating Radar (GPR). All of the above methods were used in conjunction with strip chart recorders which provide a continuous record of all of the data. A description of each of these techniques is included in the appendices.

RESULTS AND DISCUSSION

Each of the geophysical methods used provided an element of data necessary to determine the trench boundaries and provide some data on the depth of trenches. The systems approach of utilizing magnetometry, metal detection, electromagnetics and ground penetrating radar provided a higher confidence level in the detection and location of the buried

trenches than if any one method had been used alone.

The magnetometer survey was conducted first and provided data showing the approximate location of six closely spaced buried trenches. In addition it provided information as to the relative masses of metal drums buried in each of the trenches. Each of the trenches contains approximately the same mass of ferrous metals; the center section of each trench contains more drums than its eastern or western ends. The MAG data also show the center two trenches (#3 and #4) are shorter in length than the rest. Because the trenches are closely spaced (5-10 feet apart) it was difficult to precisely locate the edges of two adjacent trenches utilizing the MAG data.

To provide the resolution necessary to delineate the boundaries, a metal detector survey was performed over the same survey lines. The data from this survey provided better resolution in defining the edges of the trenches. As with the MAG survey the MD data also showed six buried trenches with the two center trenches being shorter than the rest. The results of the geophysical survey over the trench area are shown in Figure 5.

The magnetometer responds only to ferrous metals while the metal detector responds to all metals, ferrous and nonferrous. No metals were found in the western halves of trenches #3 and #4.

In order to resolve whether the two short trenches were indeed short or whether they were as long as the others and only partially filled with metal drums, additional surveys were performed with EM and radar. The data from the EM survey provided information on bulk subsurface conductivities and correlated with both the MAG and MD data. Analysis of the EM data verified the shortness of trenches #3 and #4 as it did not show a

non-metallic conductive anomaly in the suspected trench areas. The GPR survey verified the results of the MAG, MD and EM surveys in showing that #3 and #4 trenches were shorter than the rest. In addition the GPR data showed the buried portion of the existing trench #7 to be the deepest trench relative to the others. Using this information, the existing trench (#7) appears to be approximately 15-17 feet deep and the others between 10-12 feet deep.

Metal stakes were placed at the four corners of each trench. The locations of these stakes were surveyed in and are presented in Table 1. The trench boundaries, shown in plan view in Figure 5, were determined by assuming that all metallic anomalies which formed a lineation were part of a single trench. In some cases, especially near the trench ends, the anomalies were less massive. If these anomalies were coincident with the liniation formed by the more massive anomalies, they were included as part of the trench.

Trench #4 could possibly be two closely spaced trenches since the MAG and MD data showed a bimodal nature to the anomaly in this area. It could also represent a wide trench in which drums were dumped from either side leaving the center relatively open.

INVESTIGATION OF CONTAMINANT PLUMES

OBJECTIVE

The objective of this phase of the geophysical effort was to determine the presence, location and direction of possible contamination plumes emanating from various sources in the survey area. The methods used included electromagnetic profiling and resistivity sounding. A detailed survey was conducted over an approximate 20 acre area containing the buried chemical sludge trenches (Figure 2). Other areas investigated were an abrasive dust disposal area northeast of the trenches and the sanitary landfill to the east of the trenches. In addition, surveys were conducted in the area west of the industrial complex concentrating around the new and old chemical waste lagoons (Figure 2).

SUMMARY

Data generated from electromagnetic profiling and resistivity sounding surveys provided information on contaminant plumes emanating from several sources in the 640 acre survey area of AAD. The specific sites investigated were (See Figure 2):

1) Chemical sludge trenches
2) Sanitary landfill
3) Abrasive dust disposal area
4) New Lagoon
5) Old Lagoon

Background (non-contaminant) EM values were very low, generally being less than 3 millimhos/meter (mm/m). The highest conductivity values

associated with plumes were found on top of the sanitary landfill with measurements as high as 300 mm/m. Values of around 100 mm/m were recorded in the trench and old lagoon areas. Highest values around the new lagoon and abrasive dust areas were approximately 10-12 mm/m.

All of the surveyed areas were found to have some degree of contaminant migration (See Plates 1 and 2). The direction in which these plumes are migrating varies locally depending on the relation between the contaminant source and the surrounding topography. This is related to the fact that shallow groundwater flow and hence plume migration are topographically influenced. In some cases, the actual plume mapped may be partially due to surface runoff and subsequent downward percolation and not necessarily groundwater flow (e.g., the westward extending plumes from the trench and abrasive dust areas). In general there appears to be an overall southeast direction to the regional plume migration.

FIELD PROCEDURES AND METHODS

The geophysical methods used in this phase of the survey included continuous electromagnetic (EM) profiles and electrical resistivity (RES) soundings. The EM profiles provided spatial information on the subsurface conductivities to a depth of 20 feet from the surface. The RES soundings provided a correlation with the EM profiles and some data on the vertical nature of the subsurface resistivity (reciprocal conductivity). A description of these techniques is included in Appendices A and B.

Before beginning the EM surveys, the areas to be covered were gridded or surveyed using red flags. The spacing of the grid was dependent upon the amount of detail required for each particular area.

The same grid to locate the trenches was expanded and used to deter-

mine the plume emanating from the trench area. A grid system was also set up over the old lagoon area. This grid was physically restricted somewhat by fences, roads and areas of open storage. In addition a grid system was set up around the new lagoon as well as the abrasive dust disposal area. The remaining EM data was acquired by making traverses where access permitted around the sanitary landfill and in less detail over the remainder of the survey area.

After the EM survey was completed the selection of the RES soundings was made to provide some vertical information as well as correlation with the EM in background areas and in areas of suspected plumes. Twelve RES soundings were made over the entire survey area.

The EM and RES methods provide a measure of subsurface electrical conductivities (or reciprocal resistivities). These conductivities are a function of the basic soil/rock matrix, its pore space, and the fluids which permeate the matrix. In the assessment, measurements from the suspected or known problem areas were compared to background or baseline data. In order for these methods to work therefore a conductivity contrast must exist between the fluid of interest and the local geohydrologic background values. These contrasts are created by a change in the pore fluid conductivity due to an increased concentration of natural electrolyte-rich waters or contaminating fluids. Since a contaminant may be conductive (e.g., salts, acids, free ions) or non-conductive (e.g., organic solvents, oils) it may show up as a positive or negative anomaly. At AAD the conductivities around the suspected or known sources were higher (positive anomalies) than background values. The plumes mapped in this survey therefore represent conductive anomalies which may not necessarily represent contaminants.

RESULTS AND DISCUSSION

Trench Area

Several trenches have been excavated on this three-acre site since 1971-72 (Figure 2). These trenches have been filled with drums containing sludge from paints and vapor degreasers. These wastes include trichlorethylene, chromium hydroxide sludge, and mixed metal hyroxide sludges from AAD industrial waste treatment facility, paint stripper, paint sludge, toluene, methyl ethyl ketone, xylene solvents, phosphoric acid cleaners and plating wastes (ESE, 1981).

The trenches have been cut into the side of a hill so that the uphill (east) end is generally deeper than the west end which was bermed to contain the liquid wastes. On occasion liquid waste in these trenches have breached the berm and overflow into a nearby stream (USATHAMA, 1978). In the low area to the west of the trenches, the result of these overflows is documented by the dead trees and increased conductivities down slope. In addition, most of these trees have black oil stains on the trunks about two to three feet above the ground.

Figure 6 shows the results of the EM survey around the trench area. In general, background conductivities were extremely low being less than 3 millimhos/meter (mm/m). The highest values immediately over the trenches were around 100 mm/m with average values around 30 to 50 mm/m. The data show an apparent overall spreading of a conductivity plume around the entire perimeter of the trench area. However there are two basic directional components of a plume emanating from the area. One of these is a forked lobe extending in an easterly direction with the southern fork having higher values. The other is a much larger plume extending to

the west and then turning south. Much of this westerly plume may be a result of the surface spillovers and berm failures. The topography dips in this direction and any surface runoff would follow this same path curving to the south following the drainage pattern. Shallow RES soundings verified this by showing a highly conductive (low resistivity) surface value. However ground water flow tends to follow the topography also (see section on ground water) so there may also be a subsurface origin for some of these higher conductivities.

The southern lobe of the easterly plume appears to be emanating from the end of Trench #7. This plume extends for about 250 feet southeast of the end of this trench before it merges to background levels. Based upon well measurements, ground water also appears to flow in this direction following the local topographic dip.

Resistivity data from R2 and R3 (see Plate 3 for location) show abnormally low resistivity values occurring above the bedrock which could be indicative of ground water contamination. Resistivity soundings R6 and R8, to the west, show a lesser degree of possible contaminants. This tends to support the EM results and the overall ground water flow data in the local area.

Abrasive Dust Disposal Area

The abrasive dust disposal area (about 200 x 200 feet in size) is located to the northeast of the trenches (Figure 2). It has been used for the disposal of abrasive dust waste from a sandblasting cleaning facility since 1978 (ESE, 1981). The waste includes steel shot, paint flakes and metallic chips. A berm has been placed along the northern and western boundary to contain the rainwater runoff. A small pond and an alluvial

fan exist between the disposal area and the berm to the west.

Highest EM values in this area were on top of the dust pile itself with values of 10 mm/m (Plate 1). A small plume extends to the west for about 300 feet. This plume could be a composite of surface run off from the site and ground water flow since both are in the westerly direction in this local area.

Landfill

Southeast of the trenches and to the west of Chert Road (Figure 2) a sanitary landfill has been in operation since 1970. Wastes disposed of in this landfill include cardboard, pallets, packing materials, digested sludge from the sewage treatment plant, cafeteria garbage and office waste (ESE, 1981). The existing landfill is half full, and three similar landfill trenches are buried between it and Chert Road to the east. A future landfill trench has been excavated to the west of the existing landfill.

In Plate 1 the EM contour shows a plume-like feature extending from the landfills in a south and southeast direction. EM values on top of the buried landfill trenches were extremely high ranging from 100-300 mm/m. The values around the perimeter of the landfill decrease rapidly approaching background levels within a couple hundred feet of the edge. An EM line along the western edge of the existing landfill showed little to no migration towards the west. A very small northeast trending plume can be seen in Plate 1 also. This plume tends to follow a local depression in the topography between two hills.

Two resistivity soundings R2 and R7 were made parallel to the landfill. Sounding R2 was made along the western edge of the existing land-

fill and sounding R7 was made along the chert road to the east of the landfill (See Plate 3). R2 shows the near surface overburden material to have a low conductivity (high resistivity) whereas R7 shows much more conductive materials in the near surface. As seen in Plate 1, these results correlate well with the EM data. In addition, both soundings R2 and R7 show highly conductive materials at greater depths. This information suggests the existence of a conductive landfill plume emanating in a south to southeast direction which correlates with trends in the EM and ground water flow data.

Additional EM measurements were taken in the vicinity of the southern part of Chert Road loop. These measurements disclosed an anomalous area in the southwest corner of this area (Plate 1). The highest values observed in this section were around 10 mm/m. A resistivity sounding, R3, was made along the flat bottom drainage channel parallel to Chert Road. This sounding indicates that a thin layer of low resistivity material exists directly over bedrock. In addition, this low resistivity value is of the same magnitude as possible spill contaminants to the west of the trenches (See Results and Discussion: Trenches). Such low resistivity values would not likely be expected from natural earth materials in this geologic setting.

This anomalous area could be the result of surface spillovers occurring from the trenches which, following the drainage pattern, would flow through this area. Another possible source was discovered in an Environmental Photographic Interpretation Center (EPIC) report (1981). Aerial photos in this report showed activities of vehicle and equipment storage as well as open dumping and storage of material from around 1949-60 in this anomalous area. No information was available as to what

was dumped or stored in this area.

EM surveys were conducted crossing the wooded hill south of the trenches in the north-south and east-west directions. Values were extremely low ranging from 1 to 2.5 mm/m, indicating no measurable movement or migration of contaminants directly across this topographic high (Plate 1).

Old and New Lagoon Area

In the vicinity of the old lagoon (Figure 2), a 1972 aerial photograph shows three or four bermed lagoons. Since 1960, one of these lagoons was used for disposal of liquid chemical wastes containing paint and paint stripers, plating waste and acids (USATHAMA, 1978). The other lagoons contained various chemical wastes and abrasive dusts. The liquid from the old lagoon(s) has subsequently been placed in the new lined lagoon to the west in the A Block of AAD (See Figure 2). The sludge from the old lagoon was dredged out and piled on the adjacent surface (to the north of the old lagoon) and covered with a liner. The dredged lagoon was subsequently filled to grade.

Several other phases of dumping activites have occurred in this general area west of the industrial complex. USATHAMA Report No. 119 (1978), shows that the following activities have occurred in this general area:

1) In 1947, aproximately 10,000 sodium filled tank engine valves were buried, each containing one ounce of sodium.

2) In 1974, 400 containers of 100 pounds each, leaking calcium hypochlorite were buried in this area. Many of the containers ruptured when dumped.

3) Between the 1940's and 1960, tank-truck quantities of concentrated chemicals were dumped into a pit in this area.

In addition the EPIC report (1981) shows various stages of vehicle storage over the entire area from as early as 1949. It also shows extensive land filling operations taking place in the area due south of the vehicle test track. Finally, a sewage treatment plant has been operating since at least 1949 in the southeast corner of this area.

Plate 2 shows EM conductivity contours over the area described above. Relatively high EM values prevail across this entire area.

Around the new lagoon, the EM data show a plume emanating in a northeast direction. EM values around the edge of this lagoon were as high as 12 mm/m. The leading edge of this plume is lost as it merges with other plumes to the east and is described below.

In the vicinity of the old lagoon extremely high EM values were observed, ranging from 30-85 mm/m (Plate 2). The major component of a plume feature occurs in a northeast to east direction (away from the topographic highs to the south and west).

In a very large area north and northeast of the old lagoon, another anomalous feature was detected. It is probably related to the various landfilling and disposal activities occuring throughout this area as described above. The vehicle storage in the test track area to the north and open storage areas to the east of the old lagoon precluded further data collection.

In Plate 2 it can be seen how all of these high conductivity values merge together and show a very general east to southeast migration. This figure also shows skewed EM contours around the diversion channel suggesting a shallow component of this plume is being intercepted by this

channel. Railroad tracks, buildings and other cultural features prevented extensive data collection to the east of this channel.

Two resistivity soundings (R4 and R10) were placed to the east of the drainage channel (See Plate 3 for locations) to provide confirmation of the conductivity plume delineated by the EM data. RES sounding R4, parallel to the channel, supports the existance of a plume in this area. RES sounding R10, parallel to the main diversion channel (Dry Creek), indicates lower conductivity (higher resistivity) material than that indicated by R4. These data correlate well with the EM data in showing a general decrease in the conductivity of the plume from west to east.

INVESTIGATION OF DEPTH TO BEDROCK

OBJECTIVE

The objective of this phase of the survey was to determine the general depth to bedrock over the entire site and in detail in the area of the chemical sludge trenches. The geophysical methods used were seismic refraction and electrical resistivity soundings. In addition, available drill logs and existing geologic literature were used to assist in interpreting the data generated from the geophysical work.

SUMMARY

Regional bedrock throughout the study area can be described as a planar surface dipping gently to the south-southeast. Local elevation variations in the bedrock surface are often expressed as topographic relief such as hills or valleys. The bedrock surface was found to be highly irregular in the area of the open sanitary landfill trench (seismic line S4). Through the literature, geologic logs and resistivity data, evidence of possible fracturing or faulting was identified in the vicinity of the plating facility. The sinkhole in the northern part of the study area appears to fall on a lineation formed by sinkhole features associated with a possible fracture trend.

FIELD PROCEDURES AND METHODS

Available drill logs were reviewed from a variety of sources. These drill logs had been collected over several years of ongoing efforts at Anniston Army Depot. Few drill logs reflect any effort to identify bed-

rock. Drill logs which identify bedrock as "rock refusal" do not agree with the geophysical results reported in this investigation. Bedrock identified in drill logs as "rock refusal" can generally be interpreted as isolated boulders, bedrock remnants, chert fragments or an isolated highly irregular bedrock surface. Drill logs which identify bedrock as "limestone" tend to agree with the regional trend and the geophysical results.

Six seismic refraction lines (normal and reverse) were run at selected locations (Plate 3) throughout the study area. Bedrock depths identified with this geophysical method place the bedrock surface slightly deeper than reliable drill logs because the method looks at massive rock rather than localized weathered or irregular surfaces. Seismic data showed local variations in the overburden materials as well as an irregular bedrock surface.

Twelve vertical electrical resistivity soundings were run at selected locations throughout the study area (Plate 3). This geophysical method is most useful in identifying changes in bedrock materials and for approximations of bedrock depths. The resistivity data agree well with other methods used in this effort.

Available geological literature was reviewed from the US Geological Survey (USGS), Alabama Geological Survey, Alabama State Highway Department, Department of the Army and Anniston Army Depot records. Aerial photographs of Anniston Army Depot were also reviewed. A visual reconnaissance of the area was conducted. Additional information was obtained through personal communications with geologists at the Alabama USGS office.

RESULTS AND DISCUSSION

Trench and Landfill Area

The bedrock surface underlying the chemical sludge trenches and sanitary landfill area is generally a planar surface dipping to the south-southeast (Figure 6). The depth to bedrock varies from 80 feet in the north trench area to 20 feet south of the hill in the center of the Chert Road loop. Topographic highs, specifically the hill directly south of the trenches and west of the landfill, are an expression of a rise in the bedrock surface (Figure 7). The indirect effect of this bedrock high intercepting the normally south-southeast dipping regional bedrock surface is a local diversion of the ground water gradient around the hill (Plates 4 and 5).

The bedrock surface underlying the center of the open sanitary landfill trench showed considerable variations. Refraction seismic data indicate that the variation may be localized bedrock remnants overlying the bedrock surface or a high concentration of large chert fragments dispersed throughout the lateritic clay matrix of the overburden material.

No direct evidence of fractures or faulting was detected in this area. A small shallow sinkhole (depression) has been mapped on top of the hill south of the trenches and west of the landfill. This feature does not show any indications of recent activity. If this feature is an inactive sinkhole it is an indication that the bedrock in this area is susceptable to the development of solution cavities. Solution cavities (and faults or fractures) are not uncommon in this region and act as the major conduits for the flow of ground water (Johnston, 1933).

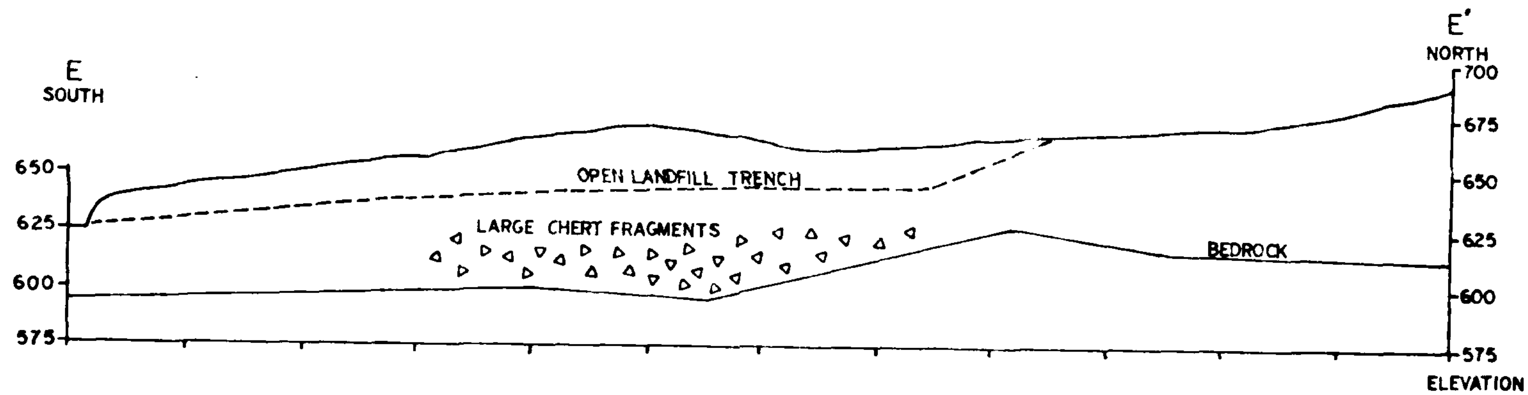


FIGURE 6. Generalized geologic cross-section through chert road loop area. See Plate 3 for location.

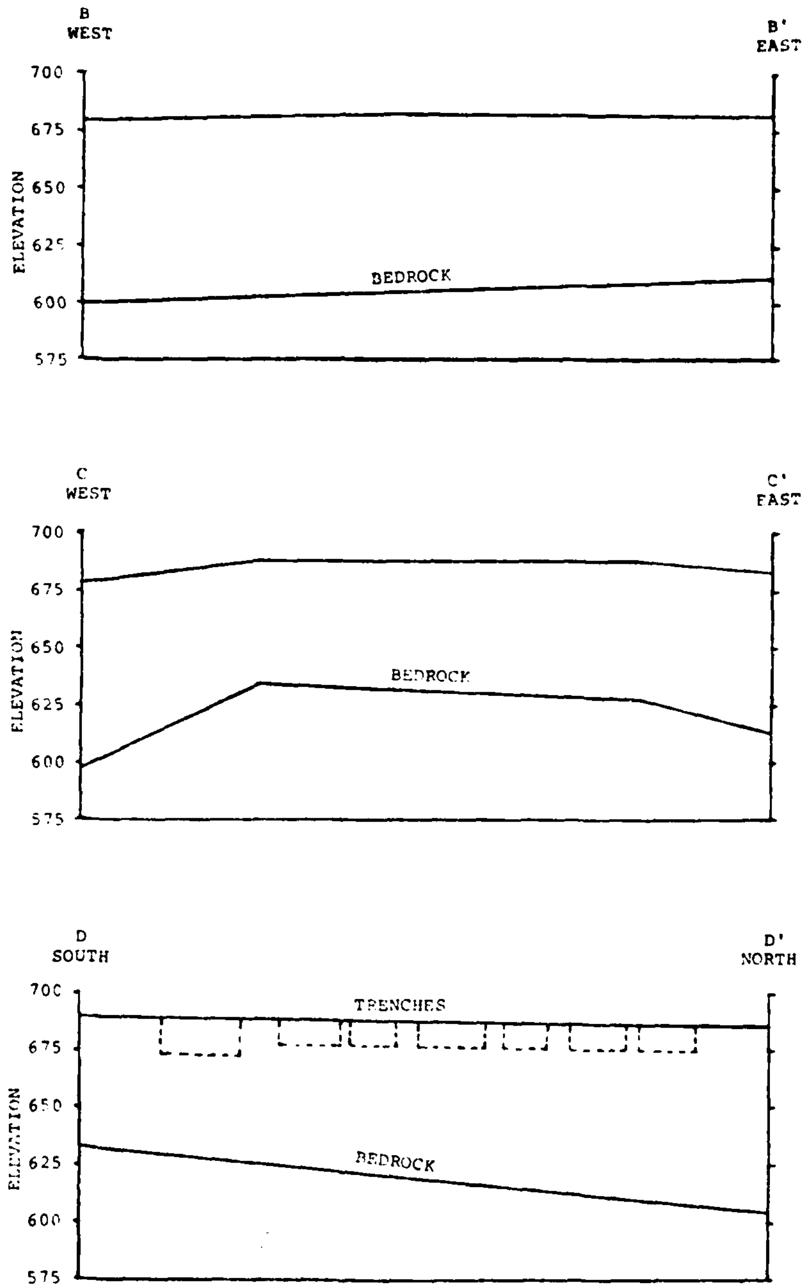


FIGURE 7. Generalized geologic cross-sections of buried trench area. Cross-section BB' is north of trenches, CC' is south of trenches and DD' is through the center of the trenches. See Figure 8 for locations.

South Area (South of Chert Road)

The bedrock of the south area is generally a planar surface dipping south-southeast (Figure 4) and locally dipping more steeply on the south-east edge of the study area. Resistivity data indicate that the bedrock material is not the same as the bedrock in the hilly area to the north. The geologic literature also suggests that this portion of the study area is underlain by the Conasauga formation (see Figure 3). The geophysical methods indicate that depth to bedrock ranges from 20 feet near the base of the hills in the north and west to over one hundred feet near the main diversion channel.

No surface evidence was identified to indicate recent faulting, fracturing or sinkhole activity in this area. An earlier intensive drilling program was undertaken as a foundation study for a proposed Plating Facilities Building along the southeast boundary of the study area (USATHAMA, 1978). The drill log data describe a steep bedrock gradient to the south-southeast approaching a 37% slope. This bedrock feature agrees with geologic literature suggesting a spur of a major fault extends into the study area in this specific location (see Figure 3). Resistivity methods agree with the available geologic literature suggesting a very complex bedrock surface along the southeast boundary of Anniston Army Depot as a result of the fracturing and faulting of the bedrock due to the main strike of the Jacksonville Fault.

Contaminant transport in fractured geologic materials is governed by the same processes as in a granular media (advection, mechanical dispersion, molecular diffusion and chemical reactions). However the existence of a fracture within the bedrock would create a more permeable zone compared to the non-fractured bedrock. The velocity of this flow is

dependent upon the width of the fracture and wall roughness (Freeze and Cherry, 1979). Even though the velocity of flow may be greater, the effective fracture porosity may be small compared to the non-fractured bedrock. Therefore the flux of water (volume of water per unit time passing through a specified cross-sectional area) through the fracture may be minimal. As the effective fracture porosity (fracture/matrix ratio) increases, the dominant movement of groundwater can be through the fractures.

Sinkhole Area

The sinkhole area is located at the extreme north boundary of the study area (Figure 2). Bedrock follows the regional trend dipping south= southeast. Local topography around the sinkhole dips east and south= southwest. Geophysical methods and local drill logs suggest the local bedrock surface generally follows the topographic surface. Seismic refraction methods detected a highly disturbed bedrock surface northeast of the sinkhole.

Figure 8 prepared by US Geological Survey in cooperation with the Alabama Highway Department presents the locations of sinkholes and depressions from available topgraphic maps. The definition of areas in which sinkholes can occur is based on location of sinkholes and available geologic mapping. Interestingly, the large and obvious sinkhole investigated here was not plotted on this map by USGS.

An immediate observation is that the occurrence of the identified sinkholes in Figure 8 line up on two axes. One axis is approximately 30 degrees east of north and the second axis is approximately 60 degrees west of north. The previously unplotted sinkhole investigated in this

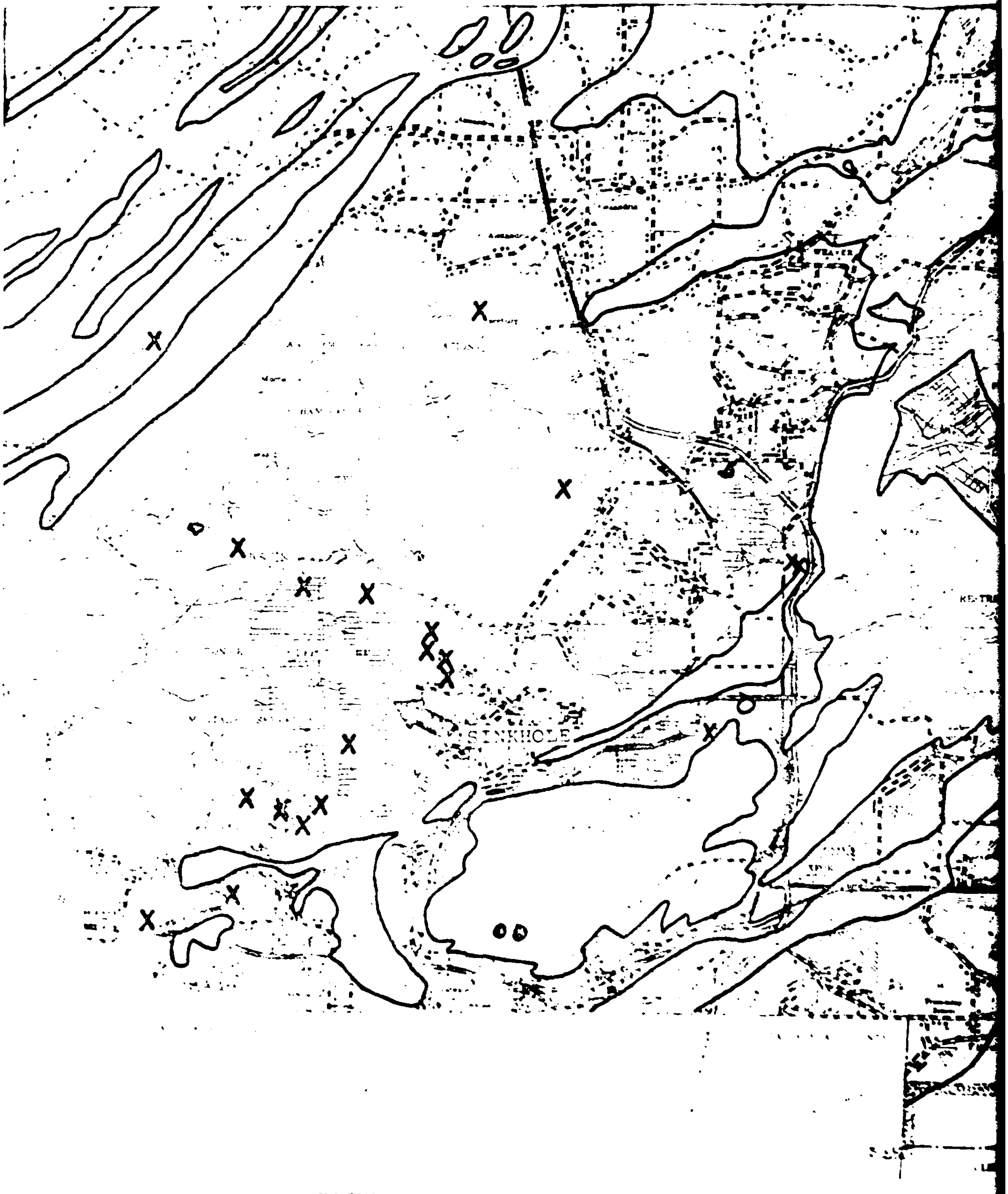
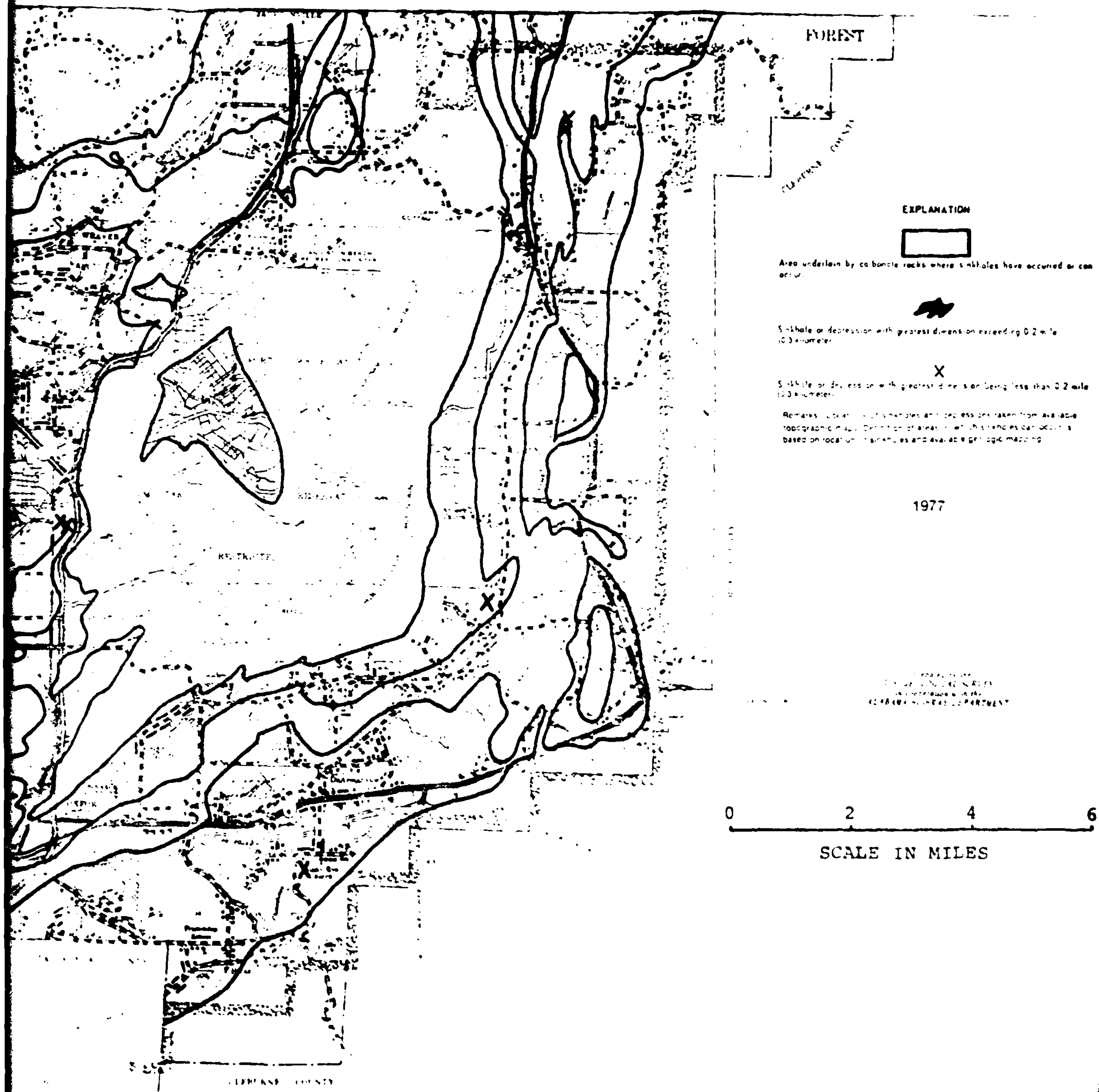


FIGURE 8. Areas in which sinkholes have occurred o[...] by the U.S. Geological Survey in cooperat[...] vestigated sinkhole was not included on [...]



es have occurred or can occur in the AAD area. Data from map prepared
Survey in cooperation with the Alabama Highway Department. Note in-
s not included on original map.

study occurs directly in alignment with the other observed sinkholes. This alignment of sinkholes has been observed on previous occasions and is a common surface sinkhole pattern (Technos, 1980, 1981, Fetter, 1980). Such sinkhole alignment is a surface expression of complex but interconnected solution cavities along weak zones (possibly fractures or faults) within the bedrock.

An electical resistivity sounding (R1) was run 50 feet east of the sinkhole. Interpretation of the resultant data indicates a horizon at a depth greater than 30 feet; this is interpreted as bedrock. These resistivity data also suggest that a lateral localized change exists in the bedrock surface or in the bedrock composition. For example, a fractured zone within the bedrock could produce the observed lateral change, appearing different than a solid piece of competent rock.

A seismic refraction survey (S1) was also run 50 feet east of the sinkhole. A complex bedrock surface was encountered at depths varying from 14 feet near the sinkhole to over 70 feet along the refraction line (see Figure 9). The lateral complexity of the seismic data agrees with the resistivity data in suggesting a lateral variation in materials. The orientation of this anomalous bedrock feature is from the sinkhole to the northeast which follows the same alignment as seen in Figure 8.

Figure 9 presents a generalized geologic cross-section of the subsurface east of the sinkhole. A comparison of the drill log of a nearby observation well (2-17) suggests the water table and the bedrock slope steeply to the east.

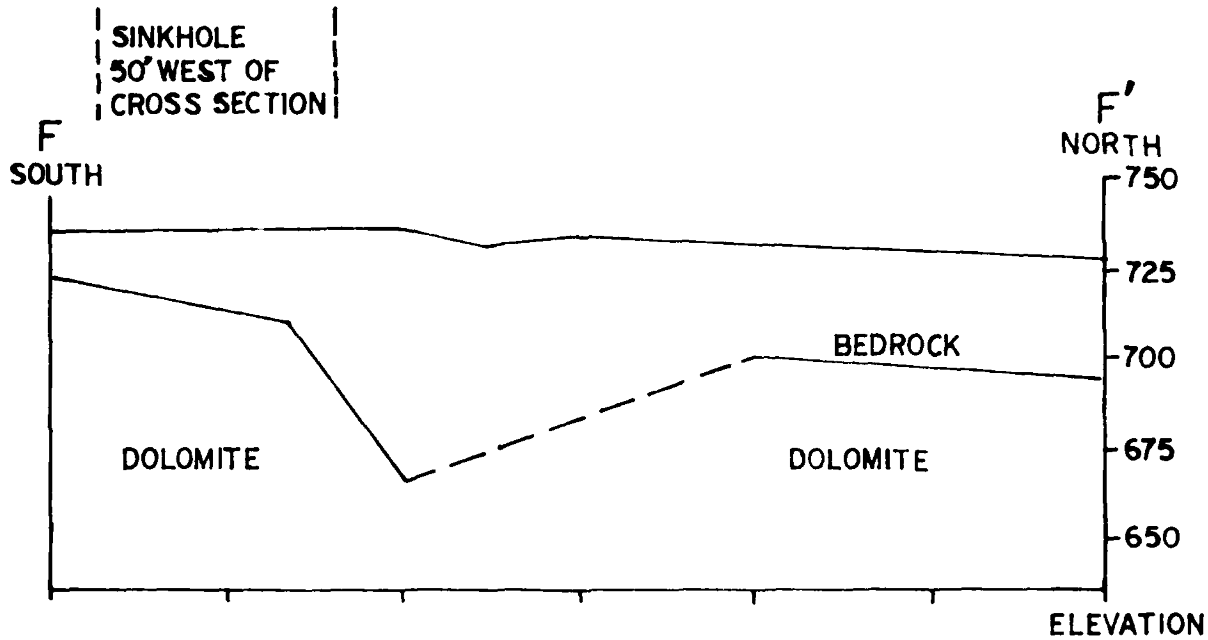


FIGURE 9. Generalized geologic cross-section of sinkhole area. Approximate North-South axis is located 50 feet east of the sinkhole (See Figure 8).

INVESTIGATION OF GROUND WATER FLOW

OBJECTIVE

The objective of this phase of the geohydrologic assessment performed at AAD was to provide an overall evaluation of the regional and local direction of ground water flow. As part of this evaluation, water table contour maps were derived from water levels in each of 37 existing wells. Three sets of these water level measurements were made at approximately 30 day intervals.

SUMMARY

Shallow ground water flow in the northern part of the study area appears to be to the south and southeast. The flow in the southernmost part of the study area tends to the east and northeast (Plates 4 and 5). All data indicate that the piezometric gradient generally follows the topography. The low permeability of the lateritic clays and fine silt to silty sand overburden material creates a low flow rate. An exception would occur in areas where the overburden materials become relatively coarse, such as gravel deposits, irregular bedrock surface and chert layers or in areas where karst-related piping activities exist.

Data indicate that ground water flow in the trench area is to the southwest off the west end of the trenches and to the southeast off the east end of the trenches. This is due to the effect of the topographic high directly south of the trenches. However, the ground water flow apparently turns south-southeast around both sides of the hill and continues in its dominant regional direction.

Ground water flow in the area near the old lagoons, new lagoon and Waste Water Treatment Plant is to the east and northeast. The topography is very flat and consequently the piezometric gradient is very low. Localized inconsistencies may be attributed to variations in the over-burden material or bedrock structure. Such inconsistencies may also be attributed to variations in well construction.

FIELD PROCEDURES AND METHODS

The following field procedures and methods were used to evaluate the regional and local ground water flow direction:

1) Determination of water levels in each of 37 wells; three sets of data were acquired at 30 day intervals.
2) Determination of water table through seismic refraction and electrical resistivity soundings.
3) Determination of flow directions derived in the contaminant plume investigation (Plate 2).
4) Review of existing data such as topographic maps and previous reports.

RESULTS AND DISCUSSION

Water Levels

Thirty seven observation wells from six earlier installations were used to determine water levels (Plate 6). Water level elevations were read three times (20 June 1981, 24 July 1981 and 25 August 1981). Water level measurements were made to within ±.01 feet. The results of these well measurements are listed in Table 2.

Potential ground water flow direction is based on contouring the

TABLE 2

	Coordinates		Elevations		
	Northing	Easting	Ground	Top of Riser	June 20 Water Level
AAD-1	1142728.251	470820.1790	686.1	687.9	668.5
AAD-2	1141723.031	471509.8950	634.2	638.0	606.8
AAD-3	1141407.070	470988.2396	630.2	634.1	607.8
AAD-4	1142349.966	470858.2676	689.1	693.1	639.2
AAD-5	1142415.804	470706.2415	688.1	692.3	642.3
AAD-6	1142534.960	470583.0635	670.0	672.5	---
AAD-7	1142514.537	471003.4383	673.2	676.7	655.5
AAD-8	1143043.513	470942.4408	688.7	692.6	659.5
AAD-9	1142904.266	470968.5858	684.9	688.2	666.5
AAD-10	1143094.304	471325.8059	719.4	723.1	686.5
AAD-11	1143257.969	471321.9944	717.1	720.1	688.5
AAD-12	1142739.092	470558.5389	662.0	662.2	647.0
* BH-1	1138630.779	469613.8445	628.2	630.0	600.3
* BH-2	1138591.488	469718.1496	626.8	628.2	599.2
** 2-3	1141566.350	471399.3375	633.0	634.7	607.7
2-4	1142313.968	471660.5557	672.5	674.2	---
2-5	1142311.427	471117.7108	661.8	662.8	632.8
2-6	1142676.647	470353.0161	655.4	657.3	645.4
* 2-7	1143627.607	471353.3432	742.1	743.5	668.0
* 2-8	1136981.312	470021.6269	614.6	614.7	606.8
* 2-9	1137003.389	470851.2688	608.3	612.2	594.3
* 2-10	1137904.879	471376.8051	620.0	621.6	605.0
* 2-11	1138377.828	471824.4791	616.6	618.1	604.2
* 2-12	1138934.630	472240.2728	616.2	617.8	597.0
* 2-13	1138512.902	470952.3544	616.2	617.7	604.4
* 2-15	1138655.967	469787.1116	624.1	625.5	599.6
* 2-16	1139292.077	468664.4728	640.3	641.5	602.9
* 2-17	1148114.073	469525.7754	729.8	731.1	---
* 2-18	1148473.084	469041.8777	749.7	751.0	701.9
* 2-79	1143634.492	470374.2173	677.8	678.7	647.8
* 3-79	1142971.838	470318.0222	660.7	661.5	650.1
* 4-79	1143272.181	470437.3639	666.5	668.0	650.4
* 3	1142544.533	473338.6197	626.2	628.3	613.3
* 6	1142617.987	473231.5064	625.5	627.9	612.8
* 7	1140445.484	469759.5839	622.8	625.5	607.1
* 8	1138543.686	470209.9224	625.9	628.2	604.0
LS-2-79	1142901.090	471339.0933	718.2	721.3	685.1
*** Sinkhole					719.9

---Indicates dry wells
*Wells surveyed for this report; previous survey data (ESE,1981) used for all othe
**All 2-# wells equivalent of Z-# wells of previous ESE report
***Stadia rod

levations Depths

ser	June 20 Water Level	July 24 Water Level	August 25 Water Level	Original Well Depth	Measured Well Depth
	668.5	668.1	664.1	50	49.8
	608.8	608.9	607.8	30	30.2
	607.8	607.7	606.3	30	33.4
	639.2	637.2	634.3	60	60.5
	642.3	---	---	50	49.3
	---	---	---	12	11.9
	655.5	658.1	652.2	40	33.1
	659.5	659.2	658.0	50	49.8
	666.5	663.7	663.8	25	25.2
	686.5	686.3	684.1	48	48.6
	688.5	688.5	688.3	60	58.3
	647.0	647.4	644.2	50	47.7
	600.3	599.7	598.0	35.5	33.2
	599.2	598.5	---	30	30.9
	607.7	607.7	---	31	28.0
	---	---	---	56.5	44.8
	632.8	631.3	627.9	56	55.4
	645.4	643.2	639.4	56	54.3
	668.0	667.8	667.7	74	74.7
	606.8	606.5	601.9	34	32.2
	594.3	593.7	592.8	28	27.7
	605.0	605.0	604.8	19	18.3
	604.2	603.9	603.3	19	18.8
	597.0	596.7	596.0	45	44.3
	604.4	604.4	601.6	28	27.7
	599.6	598.9	597.6	31	30.9
	602.9	599.5	598.2	51	50.5
	---	---	---	38	36.7
	701.9	701.1	698.9	52	52.1
	647.8	645.5	641.9	45	44.3
	650.1	650.4	645.2	30	29.2
	650.4	650.4	638.7	35	28.3
	613.3	613.1	612.8	20	17.7
	612.8	612.6	612.1	20	18.3
	607.1	606.9	605.0	26	22.0
	604.0	604.1	601.3	35	28.2
	685.1	684.5	679.1		49.5
	719.9	719.5	718.5		

981) used for all other wells

piezometric surface as derived from the observation well measurements. Plates 4 and 5 present the potential groundwater flow direction based on piezometric gradients from the 24 July and 25 August measurements.

These figures show local, topographically-induced variations in ground water flow directions. In the northern part of the study area, the flow has two components: a west to southwest flow and a south to southeast flow. These two components diverge around a piezometric high created by the hill south of the trenches. South of this hill, the ground water resumes a predominant south-southeast direction. Water levels would vary seasonally but appear to be about 20 feet below the land surface in the trench area during this period of investigation (dry season). It is possible that the base of these trenches (10-15 feet below the land surface) would be in contact with the water table during the wet season.

In the southern most part of the study area, a topographic high creates a localized east to northeast direction in the flow (see Plates 4 and 5). In addition, the piezometric gradient in the southern area is much less than that in the hills to the north.

Geophysical Measurements

Geophysical resistivity and seismic measurements agree in general with the accumulated observation well measurements. The depth to water table determined by these methods is an average depth by nature of the method. This is related to the fact that these geophysical methods integrate data over a larger volume or area rather than sampling at one discrete point. The geophysical measurements proved most valuable in extending observation well data away from the wells and identifying inconsistencies or variations in the ground water gradient where no

observation well exists.

Water level measurements in the sinkhole and the adjacent well 2-17 do not correlate, showing a difference of at least 25 feet. Seismic (S1) and resistivity (R1) data collected at this site correlate well with the sinkhole water level. The geophysical results as well as a sinkhole map of the area (Figure 11) suggest the possibility of a lineation representing a fracture or linear solutional cavity. Water levels within this zone could be higher than those of the surrounding relatively impermeable soils (in which well 2-17 is located). Another consideration is the fact that the sink may be plugged with fine sediments forming a collection basin for rainwater runoff. Composite vertical percolation and horizontal permeabilities could create the observed water level gradient between the sink and the well.

Water level measurements in the trench area wells agree well with geophysical measurements. Seismic and resistivity measurements extend data away from the observation wells. The composite results indicate that topographic high to the south of the trench area affects the groundwater gradient by forming a piezometric high around which any ground water must flow to continue its dominant south-southeast direction.

The low piezometric gradient in the flat southern portion of the study area is to the southeast, east and northeast depending on the local topography (see Plates 4 and 5). Total gradient across most of this area is less than ten feet. Geophysical methods agree well with observation well measurements. No inconsistencies in these water levels were identified using the geophysical methods.

Plume Direction

Contaminant plume direction as detected by all methods agree with potential ground water flow as defined by piezometric gradient. In the context of defining ground water flow from contaminant plumes, the contaminant most often acts as a tracer within the natural earth environment. Mapping the decrease in magnitude of pollutants away from a source is a means of defining ground water flow as related to the pollutant source. Ground water flow is effected locally by topography but generally occurs in a south and southeast flow direction over the study area.

Literature

Warman and Causey (1962) describe the water table in Calhoun County as a fluctuating, sloping surface that has irregularities comparable with and related to the land surface. They describe the general movement of ground water in Calhoun County as to the south and west. They state further that local relief of 1500 feet and a complex geologic setting make detailed interpretation of water-table maps unreliable, but generalized flow patterns can be recognized.

Water level contours for March and July 1980 (ESE, 1981) show two main directions of flow in the trench area: one toward the southeast and the other toward the west. These results correlate very well with the piezometric contour maps generated in this report (Plates 4 and 5). When used in conjunction with topographic maps, these piezometric contours provide good localized information on ground water flow. However, these very localized trends (as depicted in the ESE report) cannot necessarily be expanded to represent the regional groundwater gradients.

Variables Influencing Groundwater Measurements

In order to evaluate the responsiveness of the observation wells to reflect the true piezometric level, a simple pump test was performed on four selected observation wells (AAD4, AAD5, AAD7, AAD12). The extrapolated results showed that if a well is pumped to provide a sample, one to twenty days may be required for that observation well to return to the true piezometric level. This range of response times can be caused by variabilities in the permeability of the soil material, the amount of surface area of the screen exposed to the formation, and different volumetric displacement requirements of different size casings.

The water level measurements taken on 20 June 1981 may have been influenced by well sampling activities performed by AAD personnel. Consequently, further sampling activities were postponed until after the third water level measurements were taken. Therefore, the second and third sets of level measurements should not be effected by errors due to sampling. Inconsistencies observed between the 20 June 1981 and 24 June 1981 measurements may be explained by the responsiveness of the observation wells to sampling activities just prior to the 20 June water level measurements.

The depths of the 37 wells utilized in this investigation varied from two inches to 46 feet below the measured water levels. Observation wells used to measure the ground water table should be no more than three to six feet into the zone of saturation (below the dry season water table) (Saines, 1981). Wells much deeper than this may or may not indicate the surface of the ground water table due to composite ground water levels. A composite level differs from the water table level if the well penetrates a zone of soil (or rock) in which the hydraulic potential changes with depth (areas of recharge or discharge). The resultant water level is then

a function of the head differential, permeabilities and rate of recharge to or discharge from the system.

In a recharge area there is a component to the direction of groundwater flow near the surface that is downward or directed away from the water table. In a discharge area there is a component to the direction of groundwater flow near the surface that is upward or directed toward the water table. Recharge areas are usually in topographical high places; discharge area are located in topographic lows. Aside from the topographic effects, a lateral change in the vertical permeabilities of the soils can produce relative recharge or discharge areas. Another possible influence could be the extent of karst development within the bedrock in one area relative to another. Although all of these possibilities exist at AAD, a more detailed investigation would have to be performed to better delineate these areas.

If the hydraulic head decreases with depth, indicating downward flow, it is a recharge area. In a recharge area, a deep open borehole will show a lower level than nearby shallow water table boreholes. This may be the case at well 2-7, where the water level measurement was 20 feet below the water levels of the adjacent wells AAD 10 and AAD 11. In addition, well 2-7 is 20 feet higher in elevation creating an approximate 40 foot inconsistency in the data.

If the hydraulic head increases with depth, it is a discharge area. Although it was not the case during this (Technos) investigation, ESE (1981) reported well 2-6 as being artesian (free flowing) indicating higher heads with depth or the puncture of a confining layer. It was not obvious from the insufficient geologic log of well 2-6 if a confining layer was punctured; however several chert layers (permeable zones) were

recorded which could communicate water to this well. The bottom of this well lies approximately 46 feet below the measured water level. If this well were finished at a shallower depth (in the top of the zone of saturation), the measured water level may be lower.

The observation wells placed throughout the study area are subjected to physical abuse from vehicles and equipment operating within the study area. Inconsistencies from the previous surveyors report to measured riser pipe lengths may be caused by wells being broken off (water levels too low) or broken wells being repaired (water levels too high).

Although water level measurements were read to 0.01 feet throughout this survey, the best reliable interpretation of the data is ±2.5 feet because of potential accumulative errors.

MOVEMENT OF CONTAMINANTS INTO AND WITHIN THE BEDROCK

Potential contaminants introduced into the overburden material from trenchs, landfills, lagoons or surface spillage can be expected and have been measured to move away from the source at a rate controlled by the permeability of the overburden material. Horizontal and vertical permeability rates available from earlier soils investigations (ESE, 1981 and Golder Associates, 1978) range from 2.0×10^{-7} to 7.2×10^{-5} cm/sec or 0.2 to 74.5 ft/year. An averaged and reasonable range from 2.0 to 7.2×10^{-6} cm/sec or 2 to 7.4 ft/year can be used to estimate the mobility of contaminants within the overburden. The soil permeabilities of the trench and landfill area are slightly less than those of the flat southern area.

Overburden thickness (depth to bedrock), permeability of the overburden material, and anomalous higher permeable pathways are the key factors in estimating when a contaminant may reach the bedrock surface or how far a contaminant may travel from its source in a specified time frame. If the bedrock is karstic, as is likely the case at Anniston Army Depot, contaminants reaching the bedrock surface could easily enter the regional ground water supply of the area. It should be noted that in the unsaturated zone, the movement of contaminants will be vertical (downward) as a result of gravity. As the contaminants reach the water table, this gravity component will decrease dependent upon the relative density of the contaminant fluid to water. The downward movement of contaminants which are less dense than water (oils) would be impeded (float) and be restricted to lateral flow along the top of the water table.

Gross estimates using reasonable permeability rates with measured

overburden thicknesses indicate that a contaminant may reach the bedrock surface from 0.27 to 500 years (disregarding water table effects) from its time of introduction into the soils within the study area of Anniston Army Depot (see Table 3). Time estimates to reach bedrock in specific areas are:

Trench area	10 to 40 years
Landfill area	5 to 30 years
Lagoon area	10 to 40 years

Although the range is considerable, the probability is quite high that a contaminant from Anniston Army Depot activities has reached the bedrock surface.

In evaluating the karst nature of the subsurface bedrock, the sinkhole and associated lineation in the northern part of the study area provide potential for groundwater mobility within the underlying limestone. In the sinkhole map (Figure 8) prepared by USGS, two lineations can be seen. The studied sinkhole falls in line with the northeast striking lineation. The seismic and resistivity data tend to support the existence of an anomalous area coincident with this lineation to the northwest of the sinkhole. All of these data indicate the potential for karst development in the underlying bedrock.

In the hill south of the trenches there is a local depression. Around this depression are smaller collapses, one to six foot in diameter. This localized subsidence could be the consequence of solution activity at depth.

An anomalous area delineated by a foundation drilling program at the Plating Facility Building revealed a steeply dipping bedrock surface and a steeper ground water gradient than that characterized for the surround-

Permeability

		2×10^{-7} cm/sec	2×10^{-6} cm/sec	7.2×10^{-6} cm/sec	7.2×10^{-5} cm/sec
		0.2 ft/yr	2.0 ft/yr	7.45 ft/yr	74.5 ft/yr
		YEARS	YEARS	YEARS	YEARS
Overburden Thickness Feet	20	100	10	2.68	0.27
	40	200	20	5.37	0.54
	60	300	30	8.04	0.80
	80	400	40	10.74	1.07
	100	500	50	13.42	1.34

Table 3. Mobility rate in years for specific thickness and measured permeabilities of overburden material.

ing area. Resistivity data identified an increase in depth to bedrock and a change of bedrock material south of this area. The geologic map of the area (Figure 3) infers a possible fault in the vicinity of these anomalies.

Although only limited surface evidence of paleo-karst or recent subsidence activity exists, available geologic literature indicates significant potential for such activity. A geology map of AAD area (Figure 3) shows the largest portion of the depot to be underlain by the undifferentiated limestone of Cambrian to Ordovician age. Large fractures and solution channels are occasionally found during drilling operations; springs are likewise often encountered (Warman and Causey, 1962).

The southeast corner of AAD is underlain by the Conasauga Formation (Figure 3). This formation exists between topographic highs to the north, west and south. The carbonate rocks of the Conasauga Formation are described as highly productive aquifers with good yields from individual springs. Warman and Causey (1962) attribute this to caverns and well-developed solution channels which follow joint systems and bedding planes in the limestone.

The Jacksonville fault passes immediately southeast of AAD (Figure 3). Many of the regions more productive industrial and municipal wells are drilled into the fault shear zone or adjacent fractured zones, tapping the groundwater of the Conasauga Formation. The brecciated zone of the Jacksonville Fault probably serves as a conduit to supply large amounts of groundwater along the east edge of the outcrop of the Conasauga. In addition to the wells, many springs are located along this thrust fault, including Coldwater Spring, the largest and most utilized spring in Calhoun County (Warman and Causey, 1962).

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APPENDICES

cesium gradiometer systems are used for detailed search work. The system commonly used by Technos for most search work is a fluxgate gradiometer built by Technos. This system permits continuous coverage along a line, as opposed to periodic sampling or station measurements obtained with other types of magnetometers. The gradiometer system also permits operation in areas in which a total field instrument will fail to function because of nearby metal fences, pipes and cables. This capability of the gradiometer system is possible since the sensor head used minimizes the presence of horizontal targets such as a steel fences while maintaining full vertical sensitivity for discrete targets below. This system can be carried by hand or can be mounted to a vehicle for covering larger areas.

The basic sensor sensitivity of the Technos gradiometer is one gamma with a system response of .58 gammas per foot over a two-foot vertical gradient. The response of the gradiometer generally falls off as one over the distance to the fourth power for discrete targets.

A secondary (less sensitive) magnetometer is used as a reconnaissance tool to sort out shallow and deeper targets when the instrument is used in combination with a metal detector and other magnetometers. This unit also is a fluxgate gradiometer and is manufactured by the Schonstedt Instrument Company. Its sensitivity is approximately an order of magnitude less than the Technos magnetometer with a gradient of approximately twenty inches, yielding an overall best system sensitivity of ten gammas per foot.

METAL DETECTORS

Metal detectors respond to changes in electrical conductivity as caused by the presence of metallic objects whether they are ferrous or non-ferrous. At the same time, these detectors are relatively insensitive to changes in soil moisture or groundwater conductivity. The magnitude of response from a metal detector is a function of the following parameters:

1) Target to sensor distance (response falls off as one over the distance to the sixth power)
2) Target size (the cross section exposed to the excitation field)
3) Target orientation angle with respect to the surface
4) Target geometry
5) Type of target metal
6) Degree of target metal degradation
7) Search coil size.

The advantages of increased coil size are:

1) The larger coil averages a larger cross-section of the earth, thus giving greater coverage.
2) The larger coil will detect a deeper target, all other variables being equal.
3) The larger coil will not detect smaller single targets on or near the surface.

Two types of metal detectors are commonly used by Technos. The first, a large coil (36-inch diameter) phase discrimination gradiometer, has the ability to differentiate between ferrous and non-ferrous targets. It can also provide

target signatures for non-ferrous targets, enabling a higher level of infield evaluation of buried targets. This Technos system may be vehicle-mounted or hand-held with smaller twelve or six-inch sensor coils for more local searches.

The second is a pulse induction (transient time domain type) metal detector. This type detector is available in both handheld and vehicle-mounted systems with a wide range of sensor coil sizes. The pulse indication type of detector has certain advantages under various soil and target conditions. The output of all metal detector systems can be recorded for later analysis and processing for plotting into three-dimensional perspective figures.

Both magnetometer and metal detector data may be integrated with other geophysical data to determine more confidently the presence or absence of significant anomalies along individual traverse lines and to provide a significant level of target analysis.

APPENDIX B

ELECTROMAGNETICS (EM)

INTRODUCTION

Measurement of ground resisitivty is one of the oldest geophysical techniques. Resistivity values result from conditions existing in a large volume of ground which occurs between the system's array or electrodes. The data which are obtained are a function of the site's porosity, permeability, moisture content, specific conductance of pore fluids and other soil and subsurface geochemical parameters. However, the actual values of resistivity for different geological materials and geohydrological conditions are not necessarily diagnostic in themselves; what is of importance is the way in which the resistivity values vary laterally and with depth. This measurement of lateral (or spatial) variations allows the user to detect features as a result of their relative resistivity values and shape rather than their absolute resistivities. Classical resistivity data are obtained by point-by-point measurements which may require an appreciable amount of time to collect a sufficient density of readings.

Electromagnetics (EM) measurements provide similar data as obtained using the resistivity method; these data are called ground conductivities (or reciprocal resistivities). Some of the newer EM techniques are portable permitting data to be gathered as fast as a man can walk. Therefore, the EM method has an advantage over the older resistivity method in that subsurface conductivities (reciprocal resistivities) can be collected rapidly and continuously as the operator and instrument move across the

ground's surface.

EM DESCRIPTION

The principle of operation of the EM method is shown in Figure A. The basic instrument consists of two coils and an electronics module. The transmitter coil is separated from the receiver coil by a specified distance. When energized, the tranmitter coil induces circular eddy current loops into the earth. The magnitude of each current loop is a function of subsurface conditions. In turn, each of these current loops generates a secondary magnetic field which is proportional to the value of the current flowing within that loop. A portion of this secondary magnetic field is intercepted by the receiver coil and results in an output voltage which is amplified by the instrument. The magnitude of this voltage is linearly related to the terrain (ground) conductivity.

The units of conductivity measurement are millimhos/meter (mm/m). Conversion to resistivity units is as follows:

Ohm-meters = 1000/(millimhos/meter)

Ohm-feet = Ohm-meters x 3.28

EM instruments may be calibrated to read the true subsurface conductivity within a uniform earth. However, subsurface conditions are rarely uniform. In a layered earth where each layer has a different conductivity, the reading will be dependent upon the thickness of the layers, depth of the layers from the surface, and specific conductivities of each layer. The resulting conductivity measurement is a complex function of all these conditions and is called the apparent conductivity. A strict solution for this function requires some knowledge of the layer thicknesses, depths and relative conductivities. However, not all studies

need become this involved because first order evaluations may be made by noting the relative lateral changes along a traverse (called profiling). Since data can be obtained as fast as the operator can walk, this profiling capability is a very powerful EM technique permitting large areas to be rapidly surveyed yielding continuous profile lines. These profile data may be recorded on a strip chart and/or magnetic tape recorder. This qualitative method can often describe the location, shape and/or the periodicity of a feature whether it is a clay deposit or a series of fracture zones. Armed with this type of data, along with some ground truth information including knowledge of the local geology, an evaluation of the profile(s) can be made. This analysis results in a more complete understanding of specific features and the overall setting of the site.

TECHNOS, INC. uses modified commercial EM systems which include various recording modes, high resolution capabilities, and increased and flexible scale options. Using these systems, continuous profiling can be presently accomplished at three depths: .75 meters, 6 meters, and 15 meters. The .75 and 6 meter systems are man-portable while the 15 meter system is truck mounted. EM conductivity data may also be obtained to greater depths (60 meters) using the point-by-point method.

A number of options are available infield and during post data acquisition and display. Figure B is a block diagram depicting the options possible with the TECHNOS interactive EM system. Figure C shows two data display formats: a single EM profile and a three-dimensional view of eleven parallel profile lines. The 3-D perspective is very useful in mapping general geohydrologic conditions as well as locating and mapping the distribution of anomalous conductivities as often found surrounding hazardous waste sites. In addition, these same data sets can be presented

in plan view and contoured to show local and regional trends.

Although the EM technique is ideally suited for profiling, acquisition of vertical changes in subsurface conditions (called sounding) can be accomplished. However, sounding with EM is somewhat limited compared to the resistivity sounding methods. This is due to the fact that only a limited number of discrete depths can be measured using the EM method; this is unlike the variable electrode spacings possible with the resistivity technique. Although the resistivity method may yield more data, it requires more time to make the measurements.

The principal value of EM conductivity data is to provide continuous, high resolution data in an extremely economical manner. This permits reconnaissance investigations to be performed rapidly and effectively in defining the locations and extent of problem areas. EM methods have proven to be vital to geotechnical problems, geohydrological assessments and environmental studies.

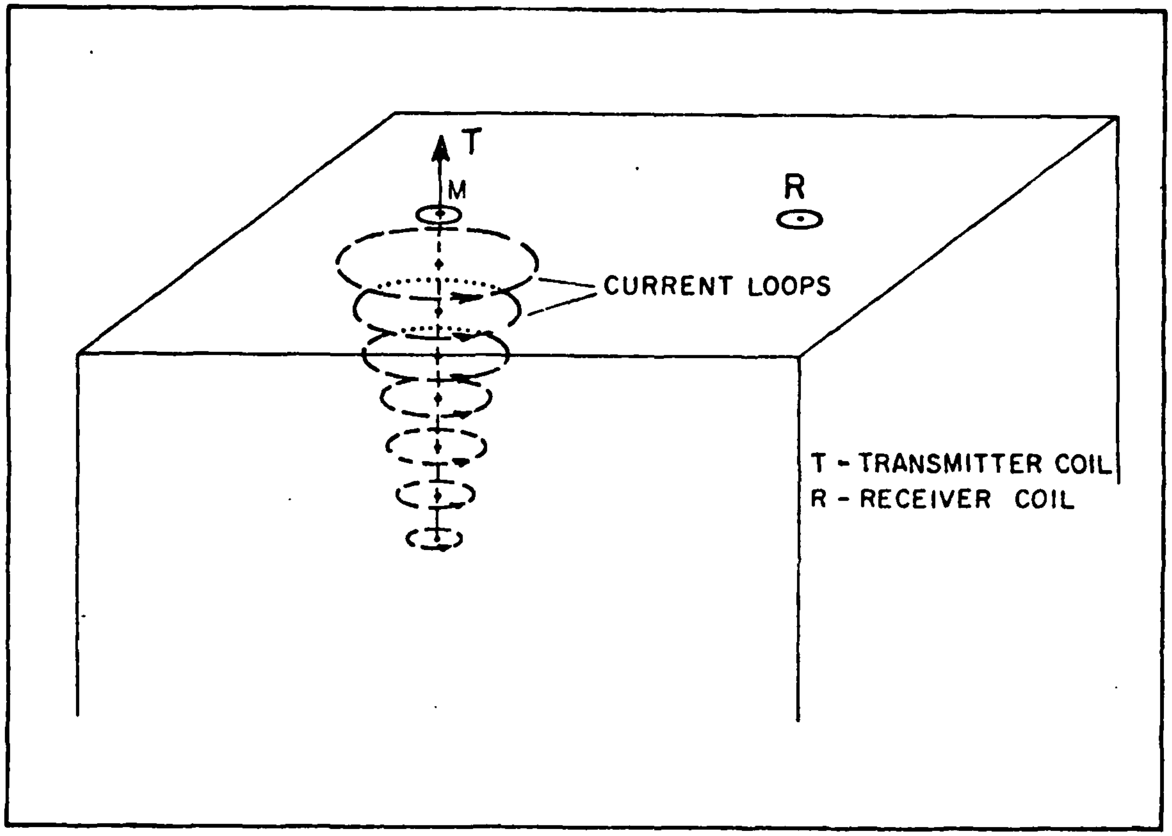

FIGURE A. Character of Induced Current Loops in Ground from EM Transmitter Coil.

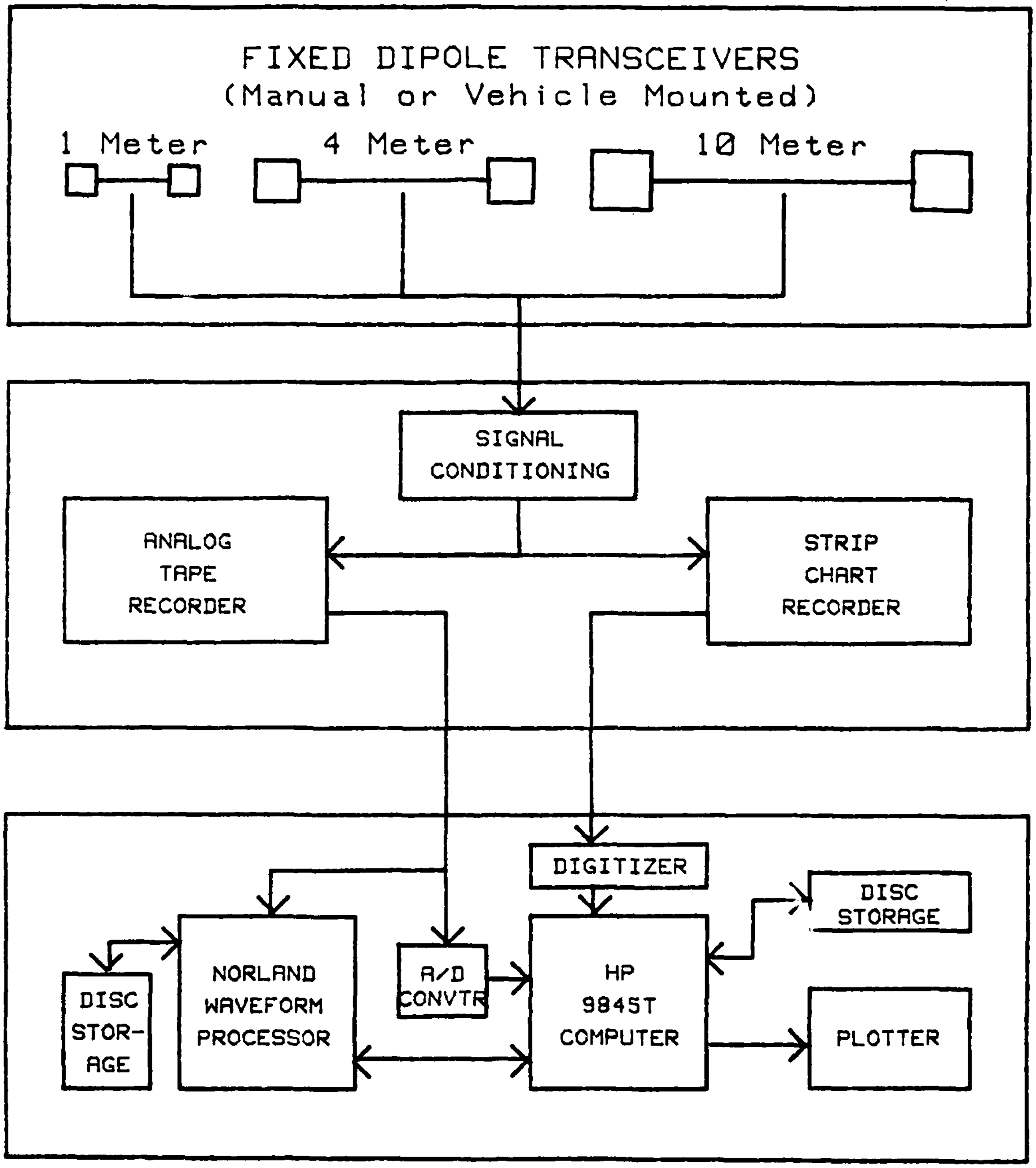

FIGURE B. BLOCK DIAGRAM OF THE TECHNOS CONTINUOUS PROFILING EM SYSTEM.

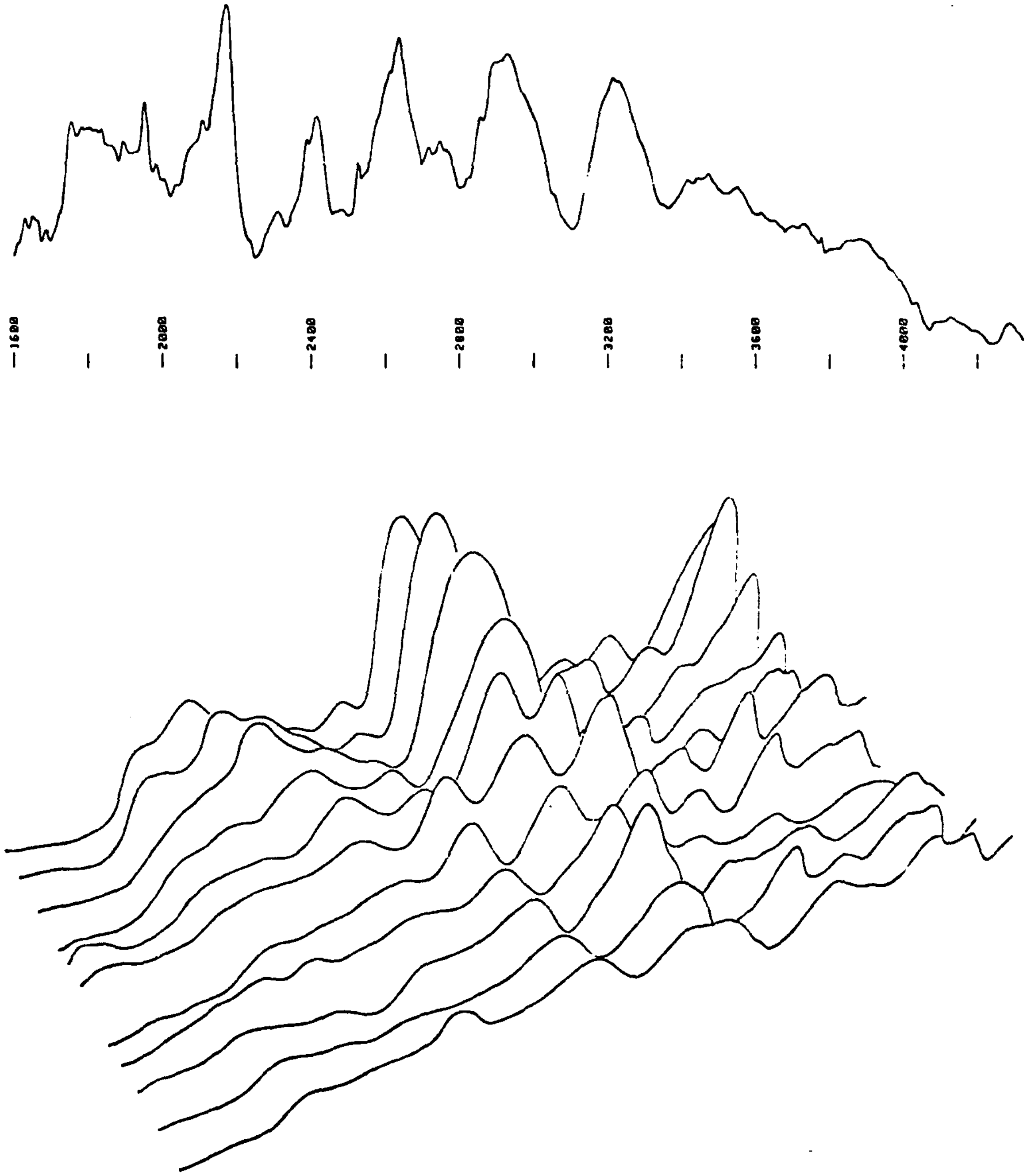

FIGURE C. Example of Single EM Profile (top) and Three Dimensional Perspective View of Eleven Parallel EM Lines With Computer Processing (bottom). The higher values seen in the data indicate fracture trends in underlying soluble rock.

APPENDIX C

RESISTIVITY AND SEISMIC METHODS

RESISTIVITY

Earth resistivity methods are based on an injection of an electrical current into the ground and measurement of the resulting surface potential (voltage) distribution. This yields a calculated value of apparent resistivity, being the result of subsurface materials and conditions present in a large volume of ground occurring between the system's electrodes. These data are a function of the site's basic materials, pore fluids, porosity, permeability, moisture content, specific conductance of pore fluids and other soil and subsurface geochemical parameters.

Resistivity values are not diagnostic in themselves for different geologic materials, however, the manner in which these resistivity values vary over the site can lead to the detection and delineation of buried geologic and hydrogeologic features. This resistivity method is called profiling.

Resistivity can also be used to specifically detect vertical changes in subsurface layers and hydrogeologic conditions; this is called resistivity sounding. In using this method, a considerable number of resistivity readings are made at a number of electrode ("A") spacings. Larger spacings provide information from relatively greater depths. In this manner, vertical changes in geologic strata as well as contaminant plumes have been mapped. This vertical information often aids in the interpretation of electromagnetics profile data.

SEISMIC METHODS

Seismic surveys employ the analysis of artifically generated (e.g., explosives or hammer blows) elastic waves in the earth in order to map subsurface geologic structures. These elastic waves travel at different velocities in materials of different densities and composition; they are also reflected and/or refracted in different ways from various materials and geologic features.

Seismic methods can be separated into two general surface techniques: reflection and refraction. The reflection technique is used to determine the presence and extent of geologic layers as well as buried anomalies. Refraction is commonly used for determination of depth to bedrock and thicknesses of soils or other unconsolidated sediments. The refraction technique can also be used to classify geologic materials using their measured compression (P) and shear (S) wave velocities.

APPENDIX D

RADAR SYSTEM DESCRIPTION

The ground penetrating radar (GPR) system is an impulse radar system which operates by radiating short-duration electromagnetic pulses into the ground from an antenna which is in close proximity to the ground's surface. These pulses are reflected from various interfaces within the earth and are picked up by the receiver section of the antenna and returned to the control unit for processing and display (this operation is analogous to that found in acoustic echo-sounding systems). These reflections occur from different soil horizons, soil/rock interfaces, rock/air interfaces (voids), man-made objects, or any interface which has a contrast in its complex dielectric properties. Fortunately, the complex dielectric constant of a material is usually related to physical and chemical parameters associated with bedding, cementation, voids, fractures, faults, intrusions, and man-made structures.

For presentation of data, GPR signals are processed and displayed by a graphic recorder. As the antenna is moved along the surface, the graphic display results in a picture-like record showing a continuous profile along a traverse, very similar to a geologic cross-section found at a roadcut. In this dynamic mode, the antenna may be towed up to 8 KPH (5 MPH) for rapid exploratory work. Detailed studies can be performed by hand towing the antenna at very slow speeds -- 0.40 KPH (0.25 MPH) -- and/or by placing the antenna in a stationary mode at specific locations.

Unfortunately, the depth of radar penetration is very site specific. Depths of 3 to 10 meters are commonly attained throughout the country; 20 meter penetrations have been

achieved under ideal conditions at some sites. This depth is reduced if ground water increases in electrical conductivity, or if there are sufficiently high concentrations of fine grained materials (silts or clays) present. For example, high concentrations of salts, montmorillonite clay or loess are highly attenuative of the radar pulse and penetration may not exceed one meter. It should be noted, however, that a lack of radar penetration or little or no data is often useful information, being most often an indicator of silts or clays or an indicator of a very homogeneous subsurface setting. GPR is an effective tool in saturated soils (freshwater) and may also be used to advantage in shallow fresh water situations as well as in permafrost and ice investigations.

The GPR technique often has applications to problems considerably deeper than its penetration depth. Knowledge of near surface features obtained from the GPR record can provide valuable information on deeper seated aspects of a site. For example, vertical piping can be seen in overlying soils in response to active cavity (sinkhole) development in limestone bedrock at depths well beyond the range of the radar. Deeper exploration can be achieved with this system by using borehole antennas.

The Technos modular radar system is composed of a modified GSSI 4700P Scientific GPR unit which is supported by an HP 9845B Computer System and a Norland 3001 Waveform Processing Computer. In normal operation, all units except the antenna are mounted in a suitable vehicle. The antenna is towed by the vehicle or manually by an operator. The system volume is about 0.34 cubic meters (0.12 cubic feet) with a weight of 123 Kg. (273 pounds). Figure A is a simplified block diagram of the GPR system.

System Description

Control Unit:

The control unit allows the operator to adjust the system for his specific antenna, desired gain, depth window and any other site requirements. This unit then transmits power and a synchronizing signal to the electronics and the pulse generator in the antenna. Subsurface reflections sensed by the antenna are sampled and returned to the control unit via cable as a low frequency signal. Further processing is accomplished by the control unit to provide an optimum signal for output to the graphic recorder and/or magnetic tape deck.

In order to be adapted to a variety of uses, the control system has been designed with many features for maximum versatility. The unit itself has a built-in microcomputer which enables real-time (or playback) processing of the data. Programs available to date for this on-board computer are background removal and filtering.

Antenna/transceiver:

The earth attenuates higher frequency signals while allowing lower frequency signals to be propagated to greater depths. However, it is these higher frequency components that give rise to the resolution of the system (i.e., the ability to discriminate between closely spaced strata or interfaces). Therefore, some intermediate point between these two extremes must be selected. Due to the modular design of the system, a number of antennas (with frequencies ranging from 80 to 900 MHz) may be readily used for maximum flexibility in adjusting to specific site requirements. Units with special characteristics as well as different unit configurations may also

be used in addition to standardized antennas. This antenna flexibility is very important since it allows the operator to select the best antenna to match the conditions at hand and achieve desired results.

During system operation a trigger pulse from the control unit initiates a capacitor discharge which drives the transmitter element in the antenna. The transmitted pulse is a quasi-gaussian pulse radiated by a broad band "bow tie" element configuration. This transmitter antenna is in close proximity and electromagnetically coupled to the ground. Whenever the receiver antenna detects a reflected radar pulse (which is travelling near the speed of light), a sampler within the transceiver samples 2000 reflected signals, reconstructing a similar waveform at a much lower audio frequency. This audio pulse is then transmitted through its connecting cable to the control unit in the vehicle.

Surface towed antennas may be either of the monostatic type (one transmitter/receiver element), a fixed spacing bistatic type (separate transmitter and receiver elements in our housing), or the variable spacing bistatic type. The variable spacing antenna configuration enables common depth point C D P measurements to be made. The lower frequency antennas (80 to 150 MHz) are generally of the monostatic or variable spacing bistatic types. They are not normally shielded on the upper side and are, therefore, subject to overhead noise due to trees and power lines. The higher frequency antennas (150 to 900 MHz) are generally of the bistatic (fixed spacing) type. They are commonly shielded on the upper side of the assembly; this is a highly desirable feature when working in a wooded or enclosed area.

These antennas have a fore and aft beam width of approximately 90 degrees inclusive angle while the side beam width is approximately 45 degrees. The pulse repetition rate is 50 KHz with a peak power of 50 watts. In operation the antenna is towed by the equipment vehicle or manually by an operator, being connected to the vehicle mounted electronics by a cable.

Graphic Recorder

The graphic recorder used in the GPR system is an EPC Labs, Inc. Model 2208 instrument. The graphic system accepts the analog signal from the control unit producing a continuous, permanent record on electro-sensitive paper. The recorder is an intensity-modulated device with the sweep of the stylus across the chart paper synchronized with the pulse transmitter trigger. Signal amplitudes above a preset threshold level are printed as black but weak signals remain white with gray scales between them. The paper moves as the stylus is swept producing a graphic profile of any subsurface features below the antenna traverse. Dark bands occur at both positive and negative signal peaks, the narrow white lines being the zero cross-over between peaks. Time calibration of the graphic profile is accomplished by driving the system with a pulse generator, resulting in 10 nanosecond bands on the graphic display. Once the relationship between the radar pulse travel time and depth is known, the chart paper may be calibrated in terms of depth.

Tape Recorder

The control unit is capable of outputting analog signals to an instrumentation magnetic tape recorder (Hewlett-Packard, Model 3960) for future processing and analysis. The

tape recorder can record profile data up to sixteen times faster than the graphic recorder. This allows much more data to be gathered in the field in a given amount of time. Then at a later time, the data may be played back into the control unit for output onto the graphic recorder.

Power Supply and Generator

A power supply module supplies the 12-volt power essential for system operation and distributes AC power to the recorder components of the system. The basic AC power for this supply module is provided by a 110 volt, 60 hertz, 1200 watt Honda portable generator.

HP 9845B Computer System

The Hewlett-Packard 9845B system is built around a 16-bit micro-computer which has 450 Kbytes of read/write RAM capability. In addition, the main memory is supported with 120 Kbytes of read only memory (ROM) and 1.4 Mbytes of on line mass storage. Peripheral equipment includes a four-color plotter, digitizer, printer and various digital and analog input capability.

The system is small in size and is used in the field when necessary. Existing Technos software permits processing of radar and other geophysical data so that these data sets may be viewed in a number of different spatial plots. This capacility, on-site, allows rapid, iterative, interaction with the data to take place in the field. This data may be then further processed for statistical trends and correlation/regression analysis.

The 9845B system is interfaced with the Norland 3001 Waveform Analyzer Computer allowing real-time signal averaging, spectral analysis and storage of discrete radar waveforms and associated analysis results.

Norland 3001 Waveform Computer

The Norland 3001 instrument is a dedicated waveform processing computer. It has the ability to input, display, and analyze one to four signals simultaneously; single keystroke commands initiate powerful routines such as differentiation, integration, signal conditioning, auto and cross correlations, fast Fourier (and inverse) transforms, power spectral density, transfer functions, etc.

The Norland has been used to identify subtle reflectors in radar waveforms as well as to accurately determine radar signal velocities in various media and determination of complex dielectric constants. Its digital filtering capabilities and stacking have enabled weak cavity and fracture data to be extracted from obscuring noise levels. In addition, it has proven invaluable in radar waveform analysis of hydrocarbons and other contaminants in soil and groundwater. The Norland's abilities are also useful for the reduction of seismic data and detecting periodicities and statistical trends in continuous EM profiles.

INTERPRETATION OF GPR GRAPHIC PROFILE DATA

An example of GPR signal structure and the resulting profile is shown in Figure B. The received signal consists of three basic components. At the top of Figure B1 is the transmitted pulse, or, more precisely, feed-through of the transmitted pulse into the Receiver section that serves as a time reference. Immediately following the transmitted pulse is a strong surface reflection. Then, at the time equal to the pulse travel time from the surface to an interface and back to the Antenna, the interface reflection appears.

The continuous stream of received pulses is fed into the Graphic Recorder and a profile, as shown in Figure B2, is developed as the Antenna is towed along the ground. The Graphic Recorder produces an image by printing strong signals (amplitudes beyond print threshold) as black and weak signals as white. Intermediate signals, such as the noise on the profile between the surface and interface reflections, are in the gray range. The profile is developed as the chart paper moves under the Graphic Recorder stylus and sequential pulses are printed to form a continuous record.

The main feature of the data is the display of dark bands that extend throughout the profile at varying depths. These dark bands are displayed in groups of three closely related bands. These three bands represent the reflection from an interface between two materials. The triple band is a characteristic of the Radar System and is caused by oscillations in the reflection of the pulse.

The vertical scale is initially time-scaled with the travel time of the pulse This travel time may be converted into a depth scale, if a knowledge of the velocity of propagation in the particular material being surveyed is known. Depth would be calculated by the following relationship:

$$D = \frac{ct}{2\sqrt{\epsilon_r}} = \frac{v_m t}{2}$$

where:

D = depth in feet

c = velocity of light = 3×10^8 meters/sec ≈ 1 foot/nanosecond

t = pulse travel time in nanoseconds

ϵ_r = relative dielectric constant of material

v_m = velocity of propagation in material = $\frac{c}{\sqrt{\epsilon_r}}$

The VHF frequency range dielectric constant and conductivity of the earth materials being probed determine the electromagnetic propagation velocity (depth calibration) and the propagation loss (penetration depth) of the GPR system.

To calibrate the GPR data, either the dielectric constant or the depth to a particular interface must be known. The conductivities and dielectric constants of various materials are presented in Figure C. These electrical parameters are dependent upon temperature, pressure, frequency, and impurities. Typical values given in Figure C are for earth materials.

Figure D lists various earth materials and their impulse rate (in nanoseconds per foot two-way travel time). This shows the approximate time that is required for a radar impulse to penetrate the material and be reflected back to the Antenna.

The horizontal scale is dependent upon the speed of the Antenna across the ground and the paper feed rate of the Graphic Recorder. The rate of sampling within the transceiver results in approximately 25 samples/sec. This results in a horizontal spatial sampling of:

17.5 Samples/Ft. @ 1 MPH

8.7 Samples/Ft. @ 2 MPH

4.3 Samples/Ft. @ 4 MPH

Two figures are included to familiarize the reader with radar data as would be obtained in normal survey work.

Figure E shows a soil profile where clean sands overlay a sandy clay loam. The top of the sandy clay loam is clearly visible; it can be seen to vary in depth along the length of the traverse.

Figure F illustrates the results of a radar traverse perpendicular to three buried pipes. Note that when crossing a pipe the response produced by a single pipe is a hyperbola.

Figures G & H are examples of individual radar waveforms as displayed on the Norland waveform analyser.

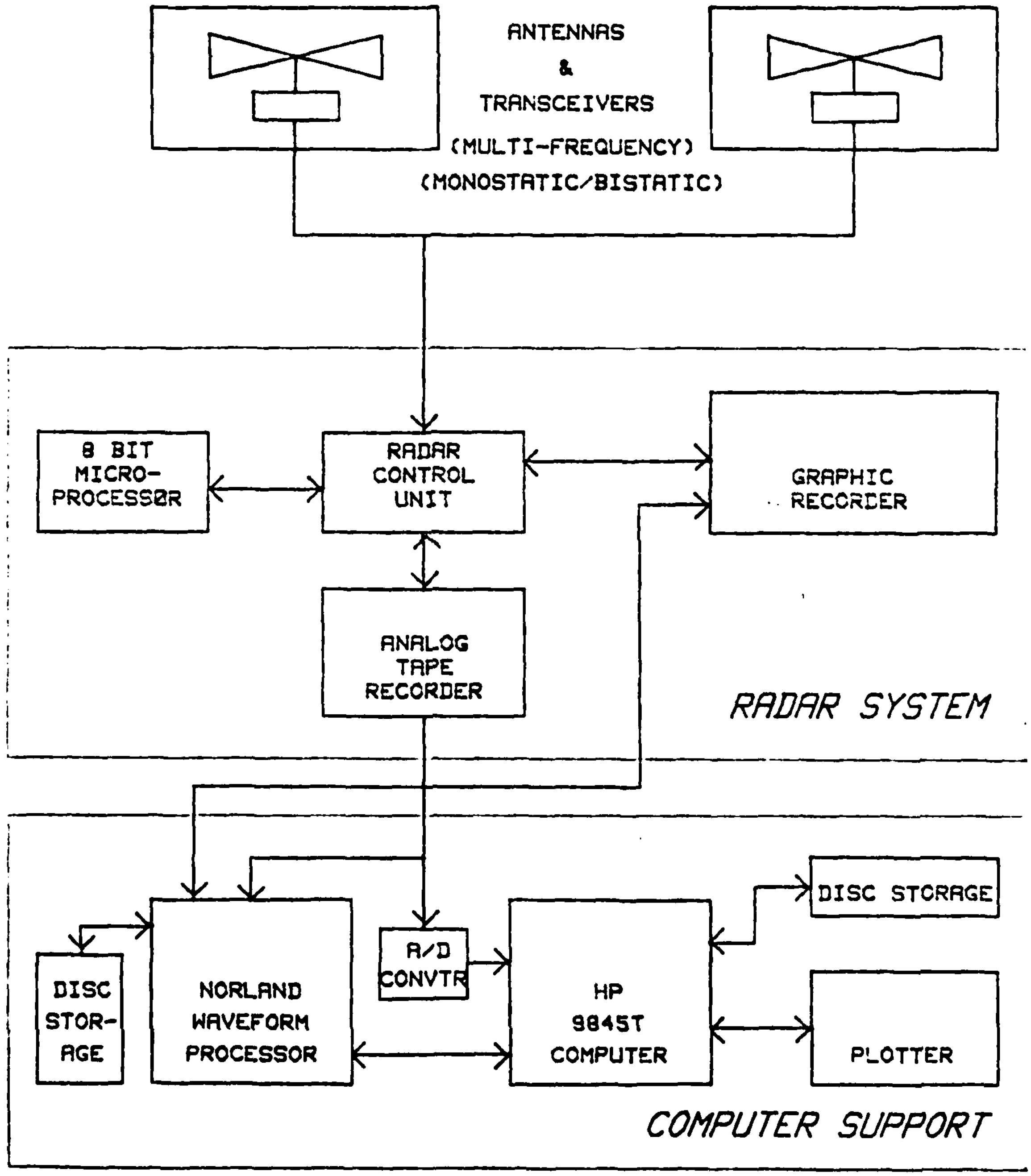

FIGURE A. BLOCK DIAGRAM OF THE TECHNOS RADAR SYSTEM.

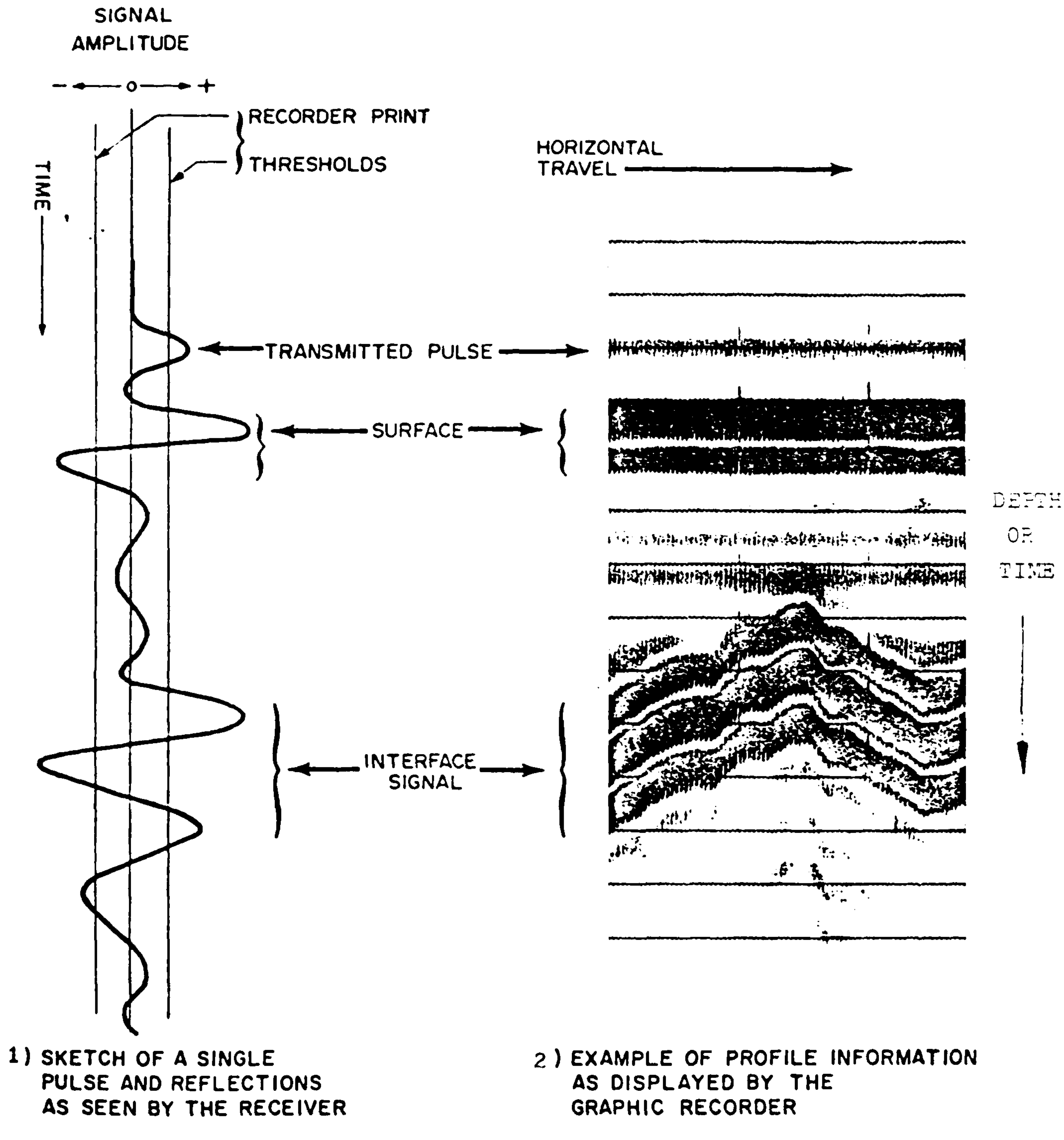

FIGURE B: EXAMPLE OF GPR SINGLE PULSE AND RESULTING GRAPHIC PRESENTATION

Material	Approximate Conductivity, σ (mho/m)	Approximate Dielectric Constant, ϵ_r
Air	0	1
Fresh Water	10^{-4} to 3×10^{-2}	81
Sea Water	4 to 5	81 to 88
Fresh Water Ice	10^{-4} to 10^{-2}	4
Sea Water Ice	10^{-2} to 10^{-1}	4 to 8
Ice (Glacial)	10^{-6} to 10^{-4}	3.2
Permafrost	10^{-5} to 10^{-2}	4 to 5
Snow Firn	10^{-6} to 10^{-5}	1.4
Granite	10^{-9} to 10^{-3}	8
Sand, Dry	10^{-7} to 10^{-3}	4 to 6
Sand, Saturated (Fresh Water)	10^{-4} to 10^{-2}	30
Silt, Saturated (Fresh Water)	10^{-3} to 10^{-2}	10
Clay, Saturated (Fresh Water)	10^{-1} to 1	8 to 12
Average "Dirt"	10^{-4} to 10^{-2}	16

FIGURE C: CONDUCTIVITIES AND DIELECTRIC CONSTANTS OF VARIOUS EARTH MATERIALS

Material	Impulse Rate (ns/ft)
Air	2
Fresh Water	18
Sca Water	18 to 19
Fresh Water Ice	4
Sea Water Ice	4 to 5.7
Ice (Glacial)	3.6
Permafrost	4 to 4.5
Snow Firn	2.4
Granite	5.7
Sand, Dry	4 to 4.9
Sand, Saturated (Fresh Water)	10.9
Silt, Saturated (Fresh Water)	6.4
Clay, Saturated (Fresh Water)	5.7 to 7
Average "Dirt"	7 to 9

FIGURE D: APPROXIMATE IMPULSE RATES FOR VARIOUS EARTH MATERIALS (TWO WAY TRAVEL TIME)

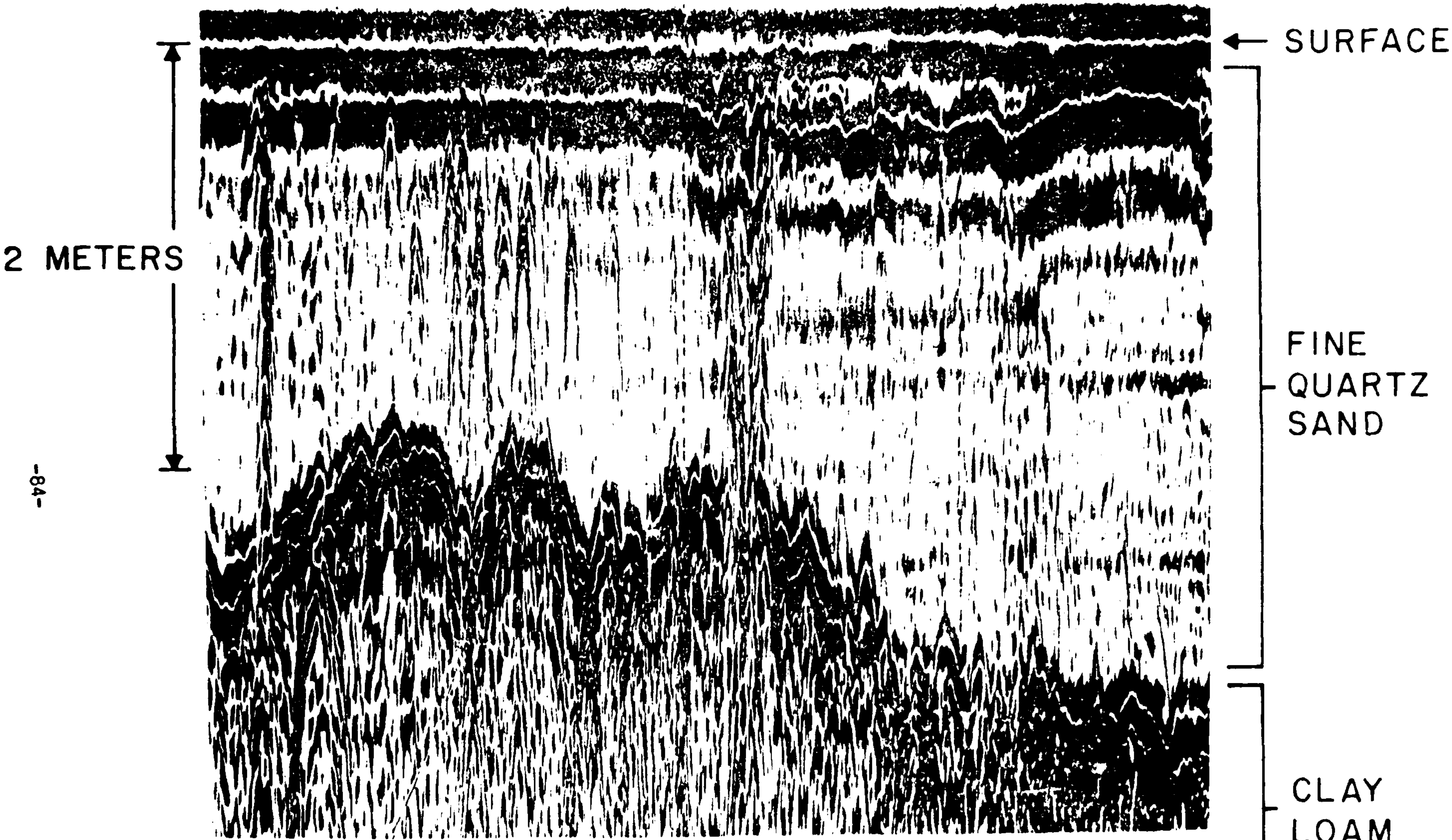

FIG E RADAR PROFILE RECORD OF CLAY HORIZON

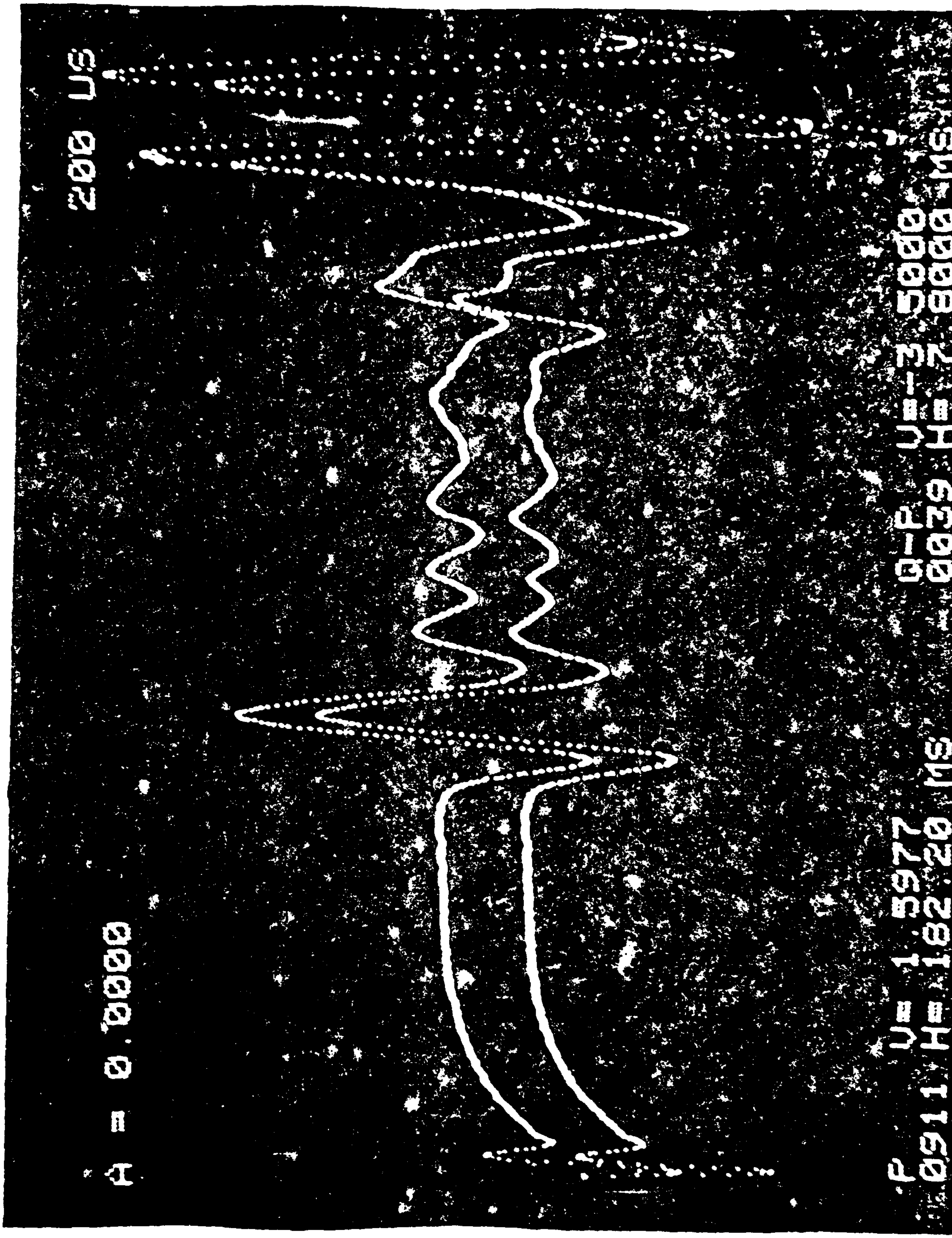

FIGURE 4: COMPARISON OF TWO SIMILAR WAVEFORMS ON THE NORLAND WAVEFORM ANALYSER

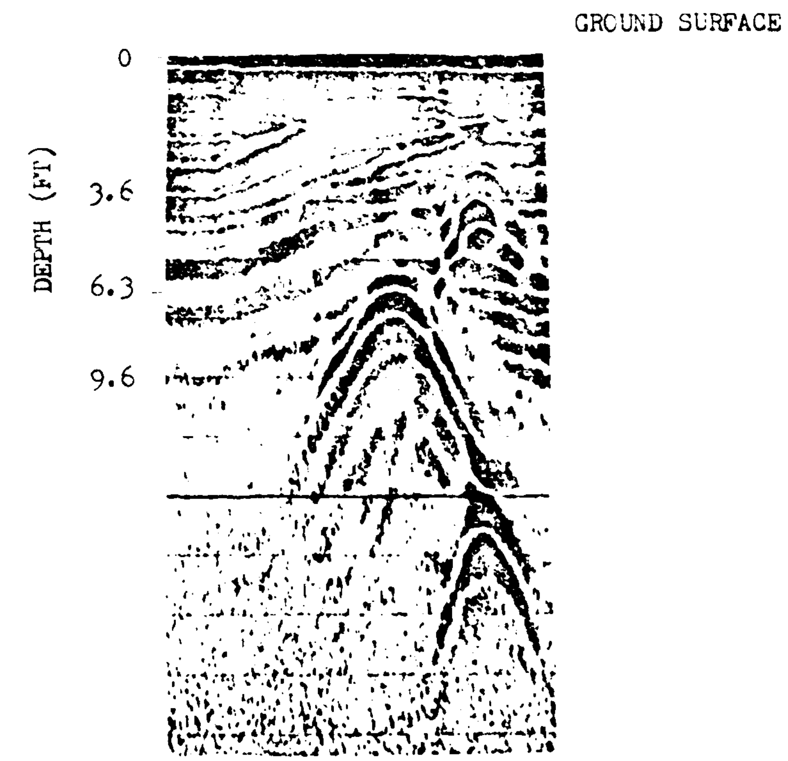

FIGURE F: THREE PIPES IN SAND (NOTE THREE HYPERBOLAS)

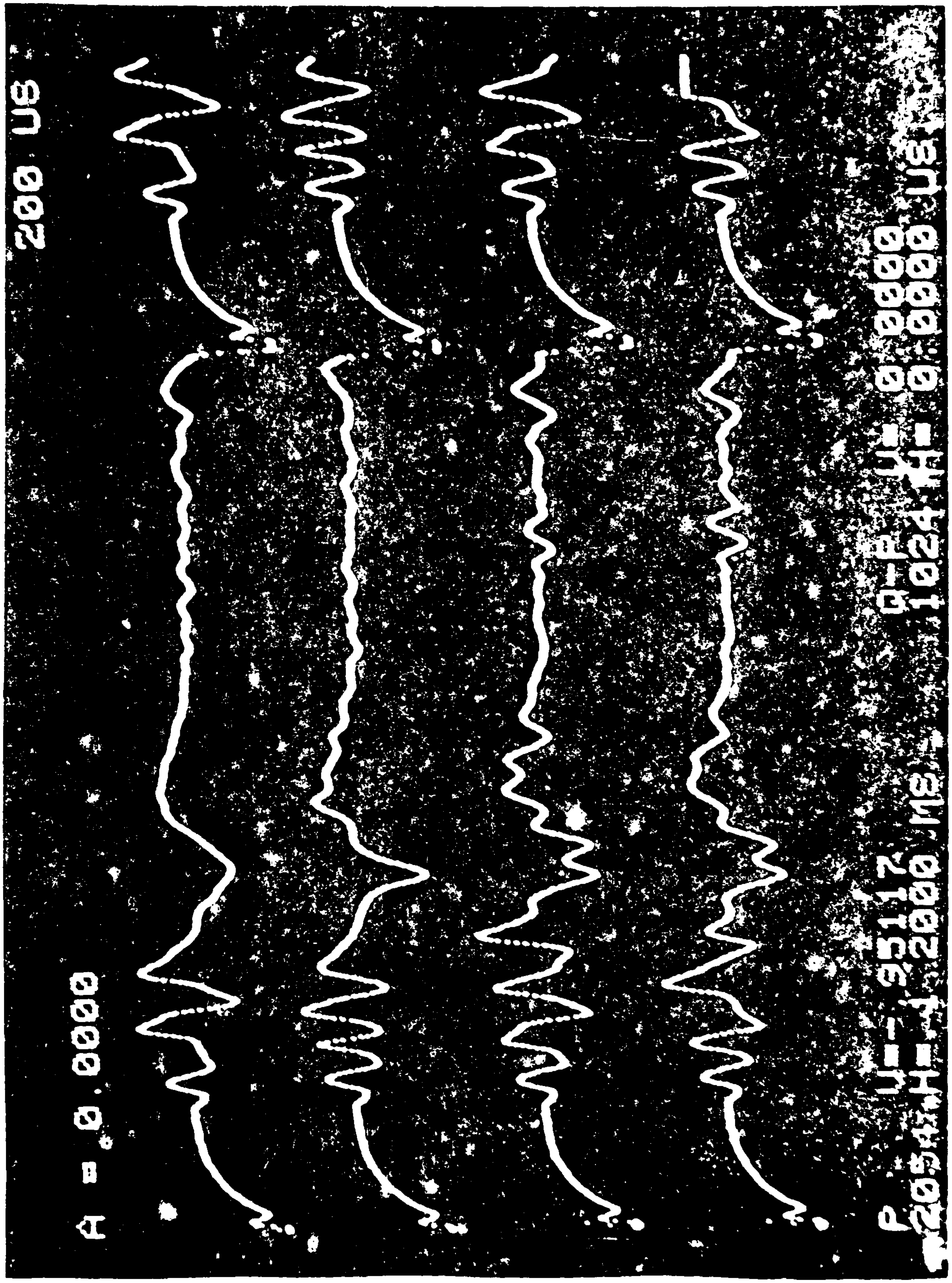

FIGURE G: COMPARISON OF FOUR [illegible]
ON THE NORLAND [illegible]

AD-A110 187 TECHNOS INC MIAMI FL F/G 13/2
GEOPHYSICAL AND GEOHYDROLOGIC INVESTIGATION OF ANNISTON ARMY DE--ETC(U)
SEP 81 M R NOEL, R C BENSON DAAG29-76-D-0100
UNCLASSIFIED DRXTH-FS-CR-81116 NL

2 OF 2

END
DATE FILMED
3-82
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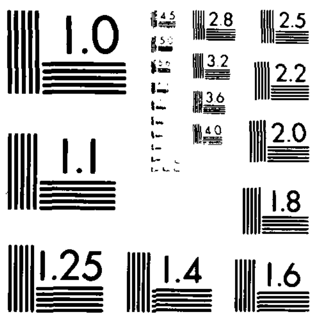
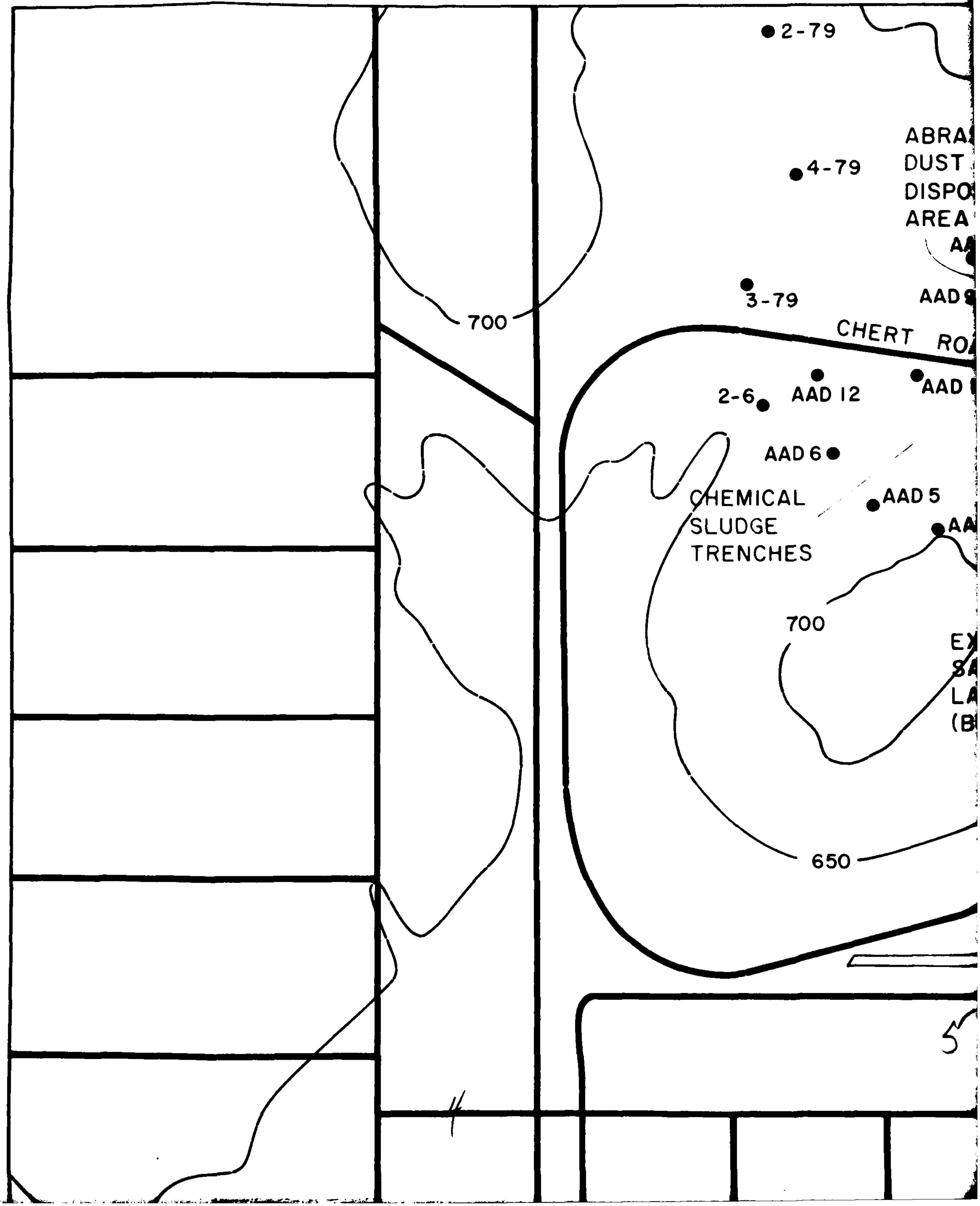
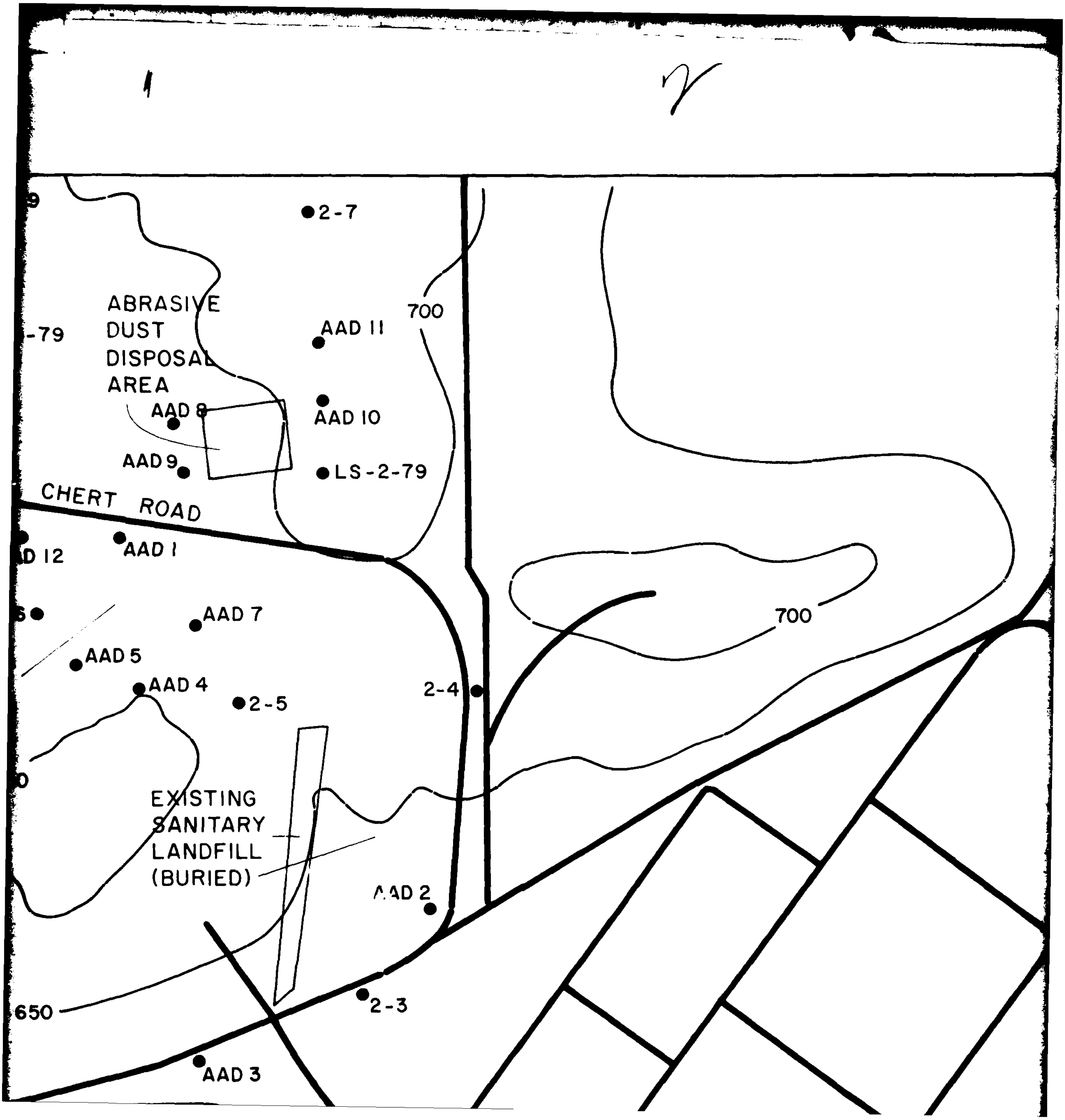
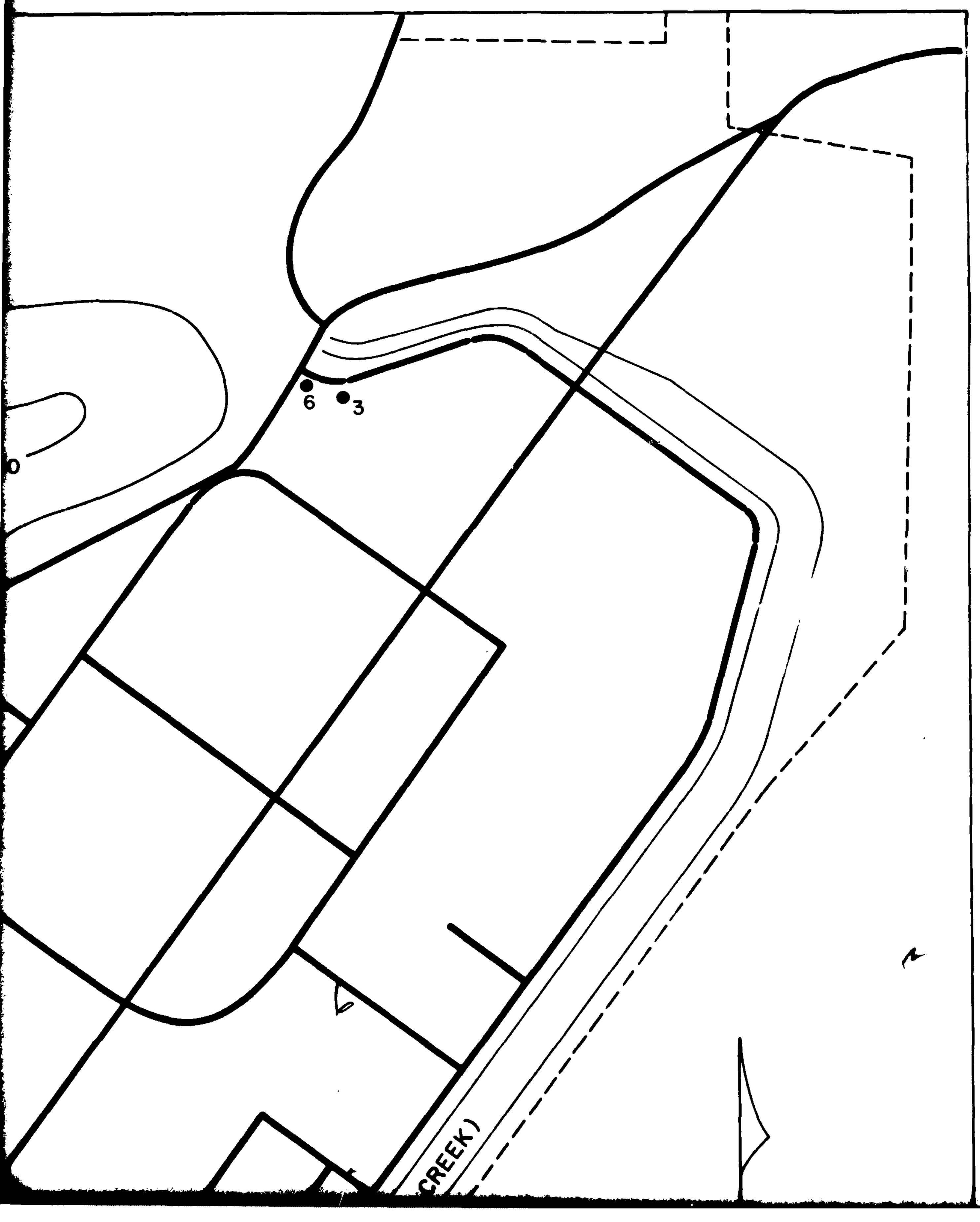


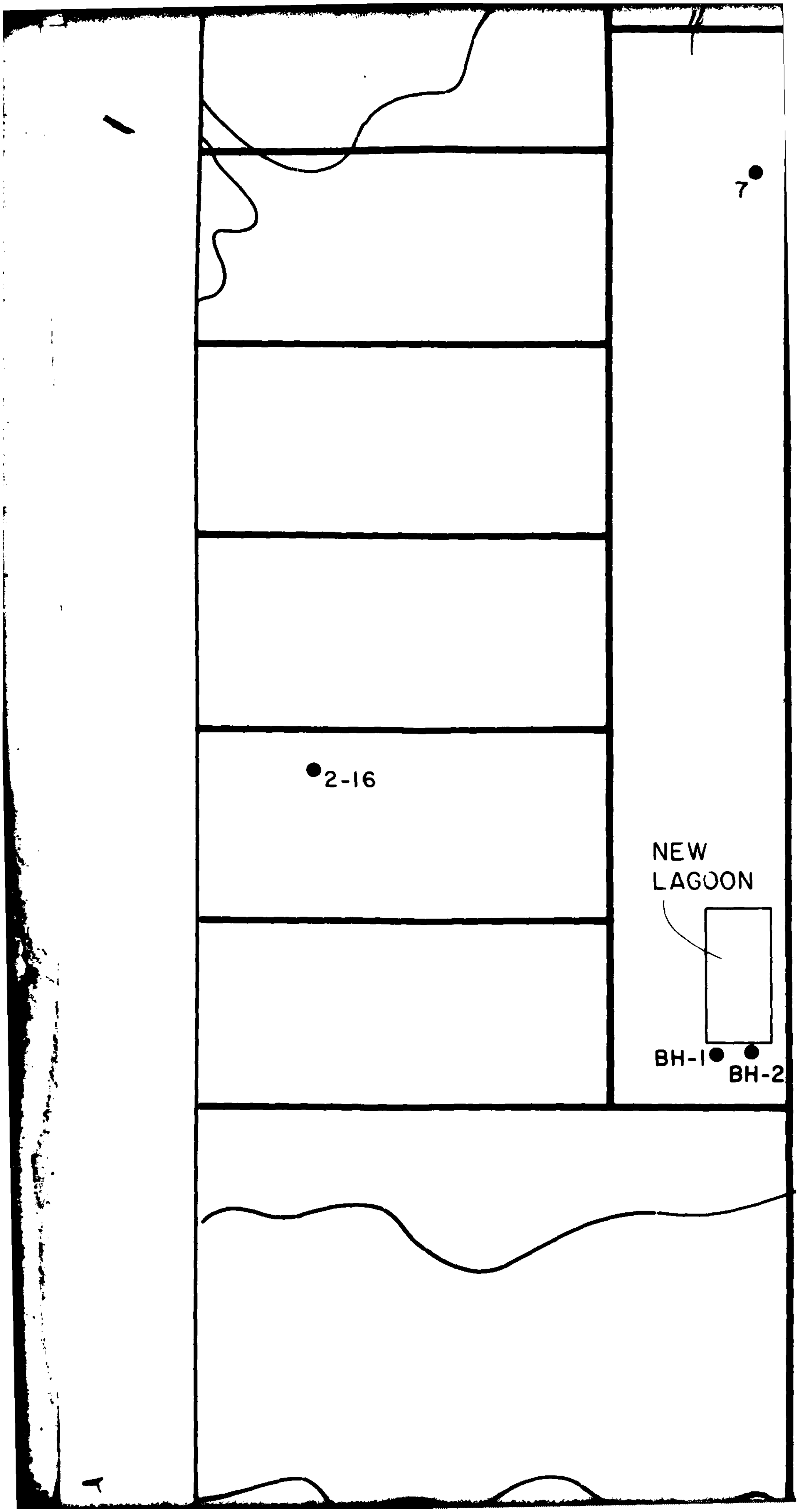
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

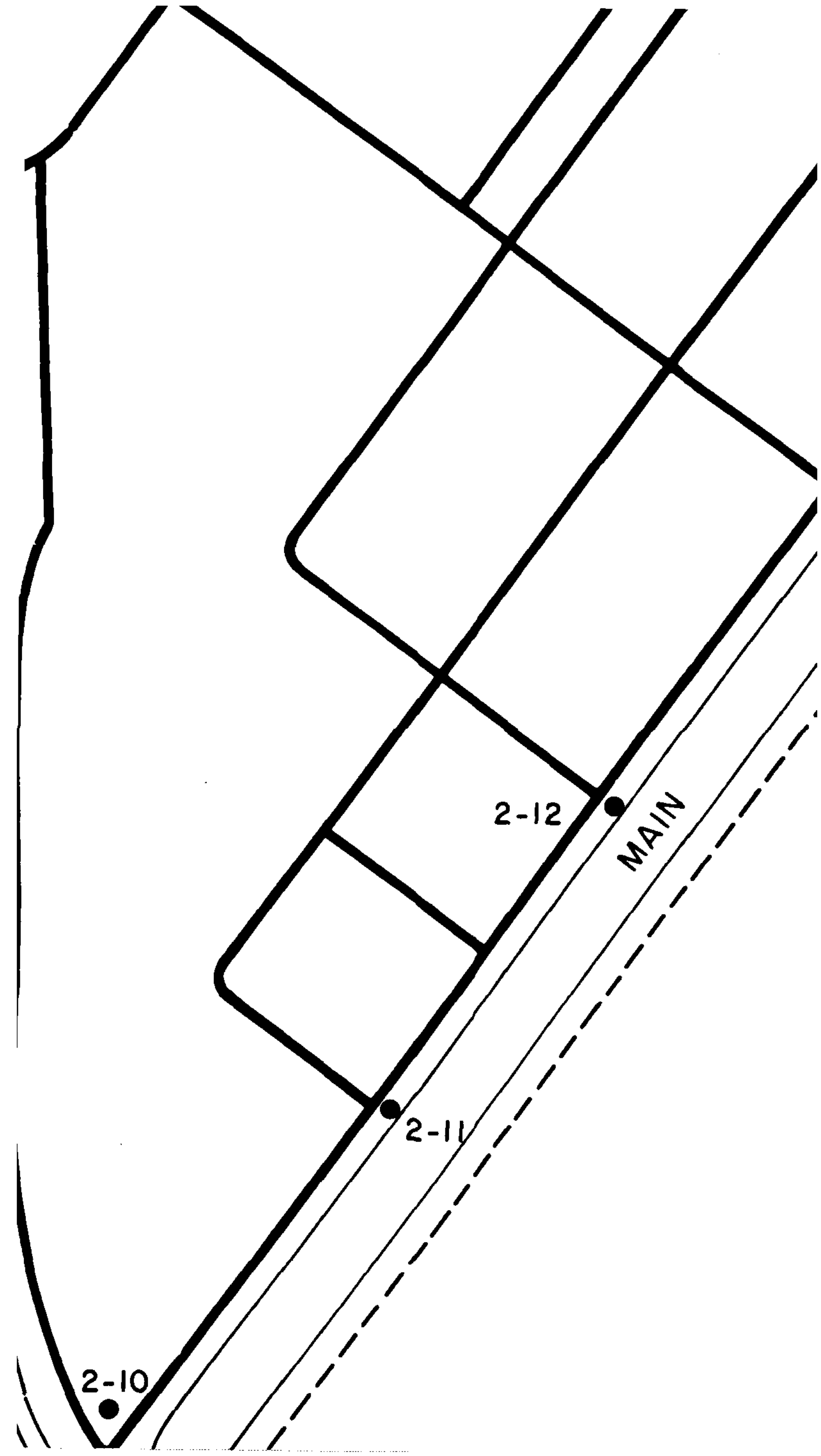


2-79
4-79
3-79
ABRA
DUST
DISPO
AREA
AAD 9
700
CHERT RO
2-6
AAD 12
AAD
AAD 6
AAD 5
CHEMICAL
SLUDGE
TRENCHES
700
650

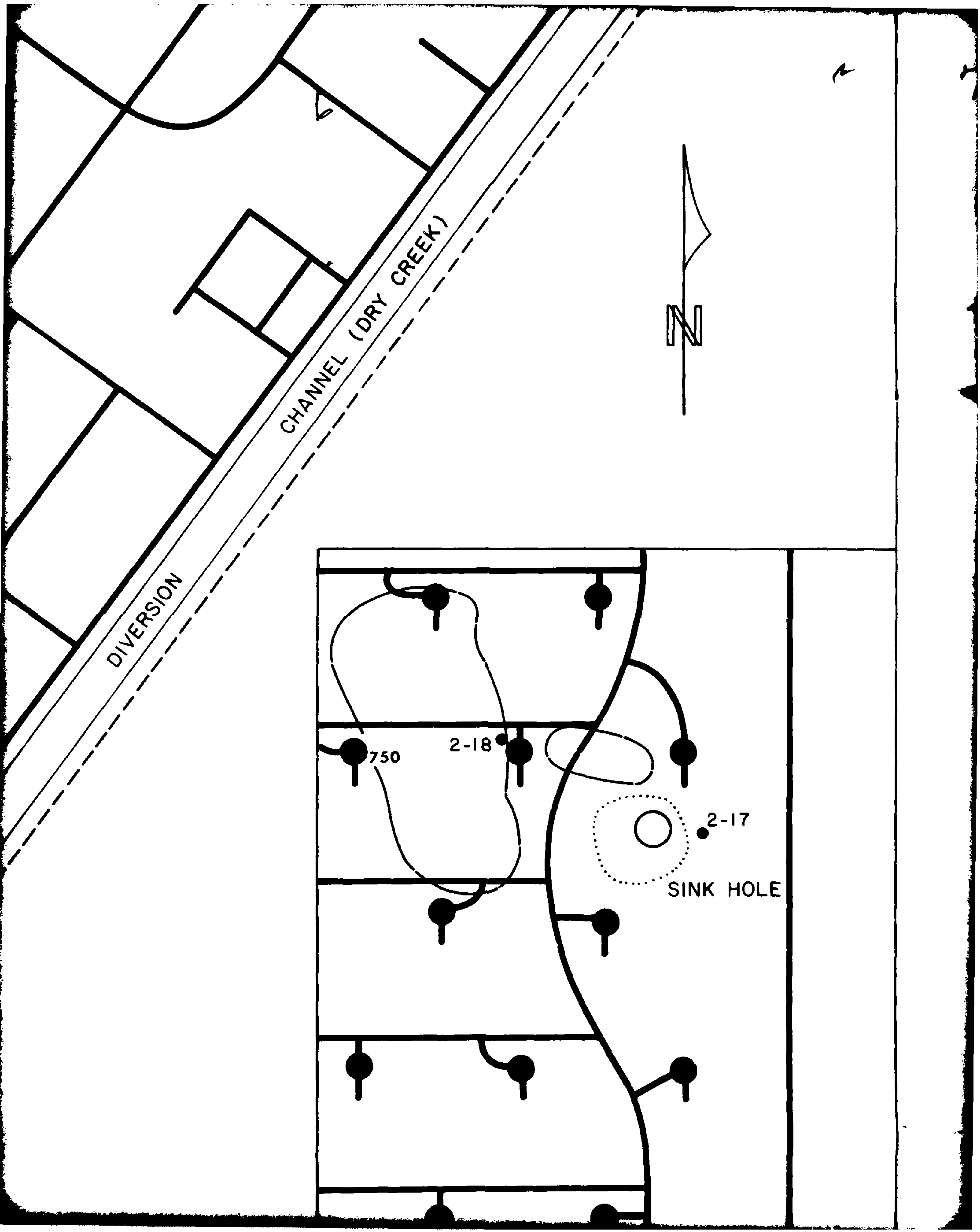

1
2
2-7
ABRASIVE
DUST
DISPOSAL
AREA
-79
700
AAD 11
AAD 10
AAD 8
AAD 9
LS-2-79
CHERT ROAD
AAD 1
D 12
AAD 7
AAD 5
AAD 4
2-5
2-4
700
EXISTING
SANITARY
LANDFILL
(BURIED)
AAD 2
650
2-3
AAD 3


6
3
CREEK)

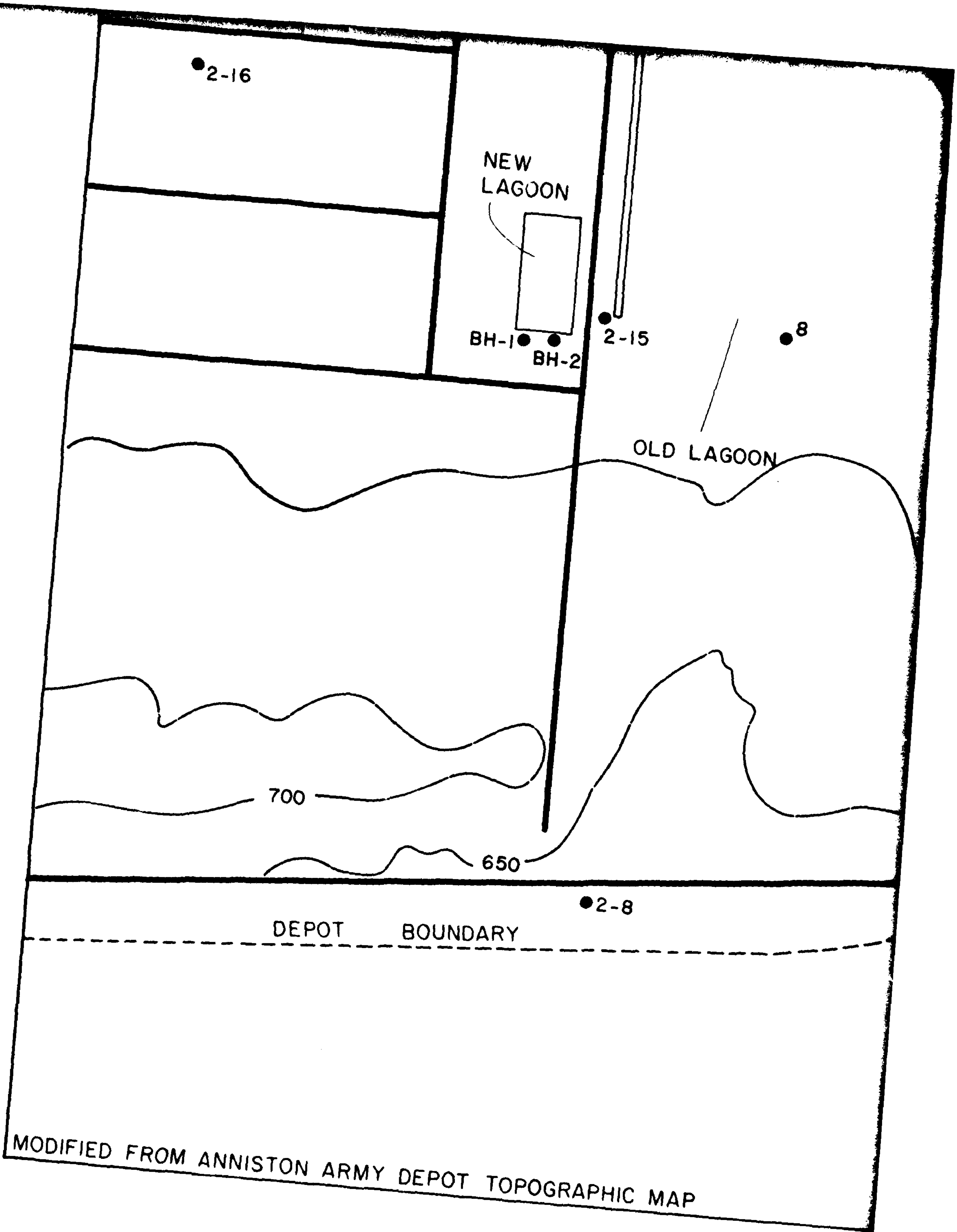

7
2-16
NEW
LAGOON
BH-1
BH-2



MAIN
2-12
2-11
2-10



DIVERSION CHANNEL (DRY CREEK)
N
750
2-18
2-17
SINK HOLE


2-16
NEW LAGOON
BH-1
BH-2
2-15
8
OLD LAGOON
700
650
2-8
DEPOT BOUNDARY
MODIFIED FROM ANNISTON ARMY DEPOT TOPOGRAPHIC MAP

8

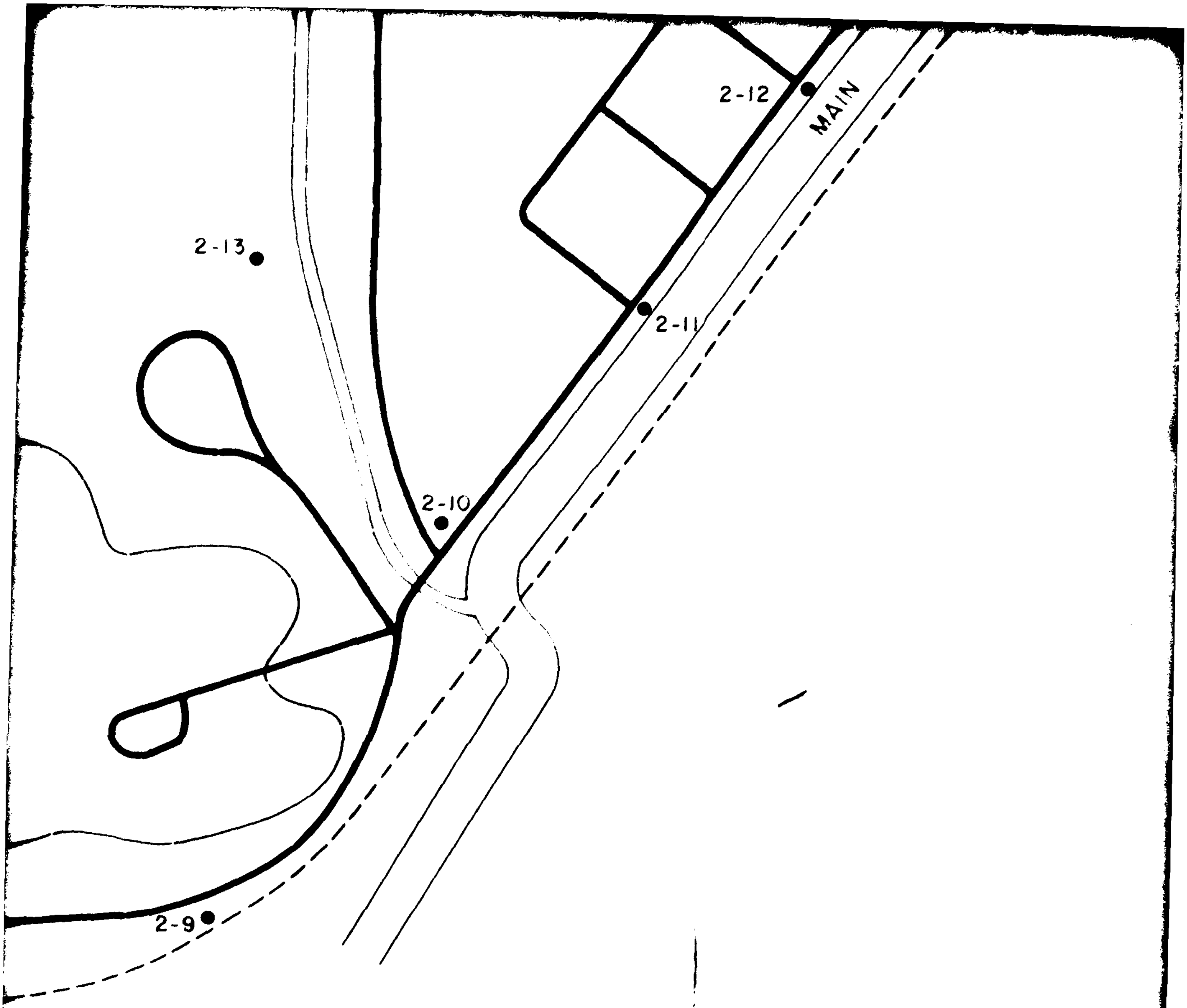


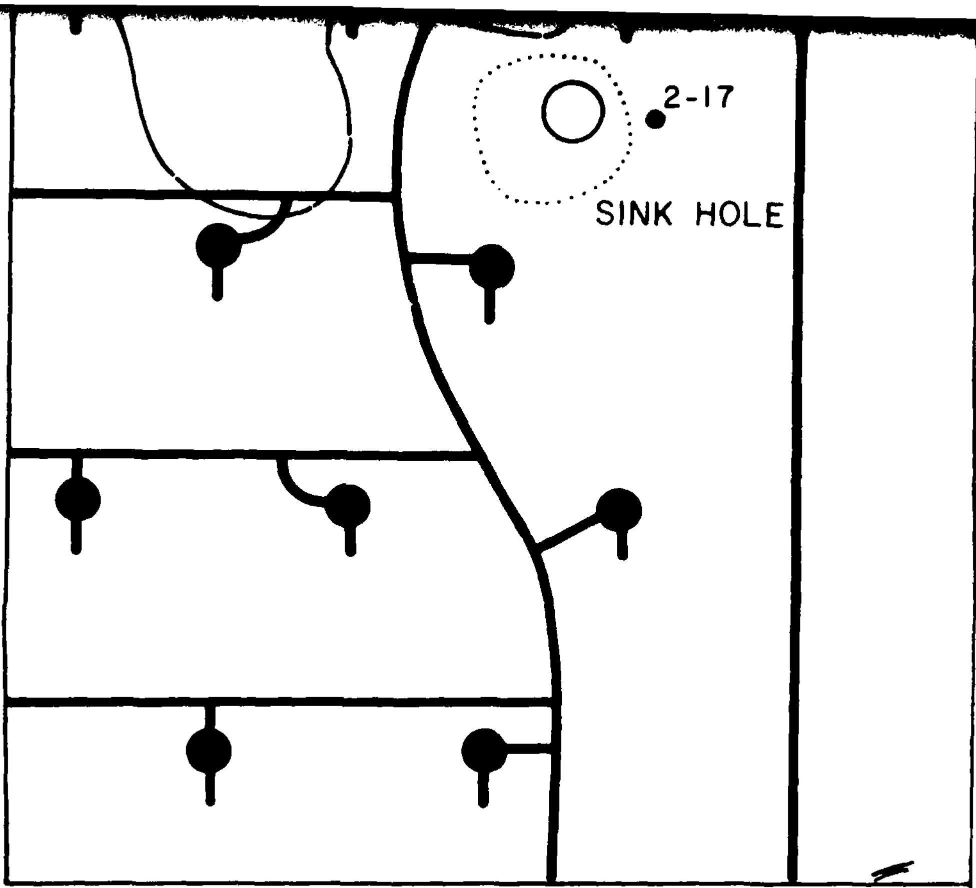
PLATE 6

TOPOGR
AND LO

ANNISTON ARMY D

SCALE 1" = 300'

ANNIS

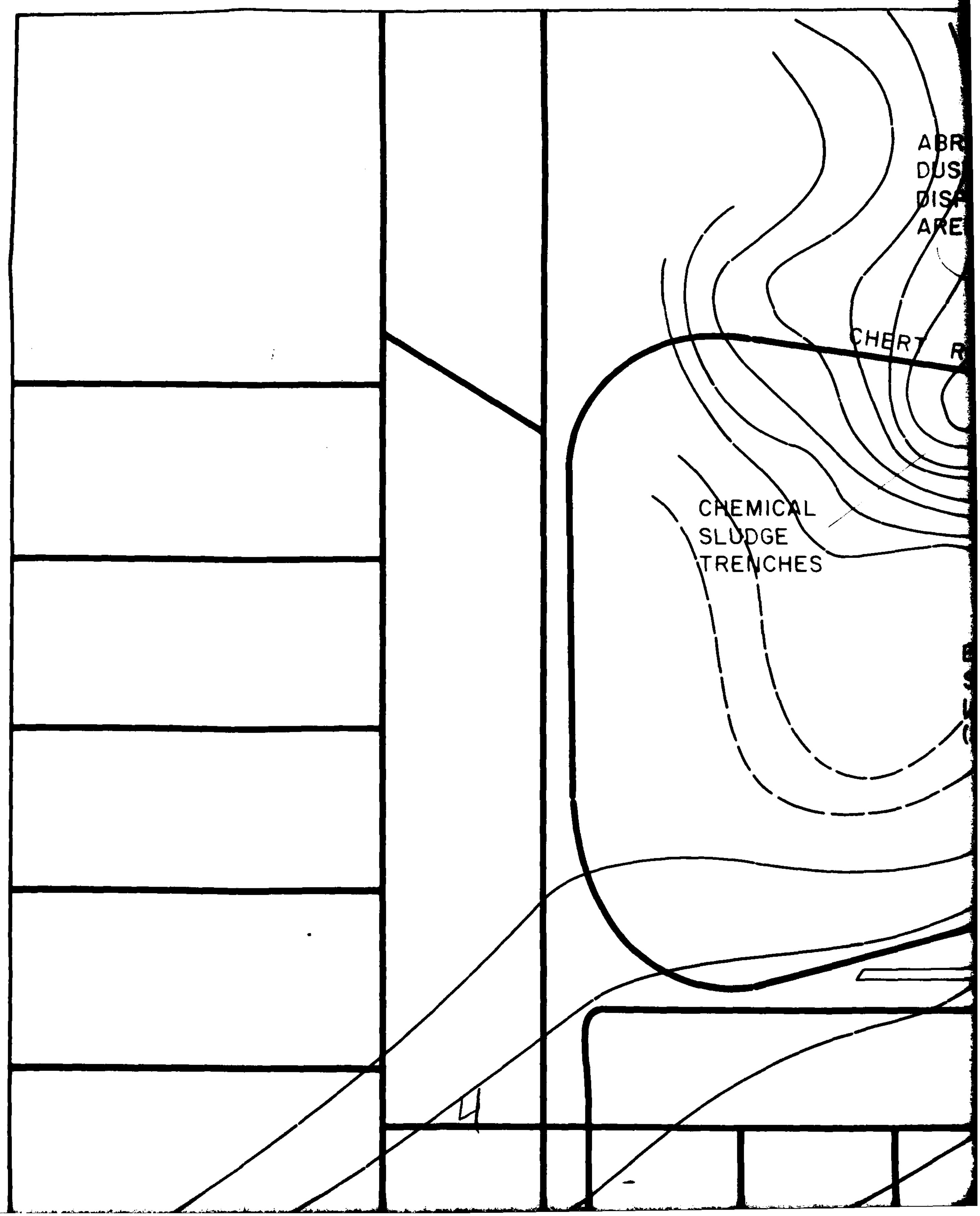


(INSET SHOWING NORTHERN SINKHOLE AREA)

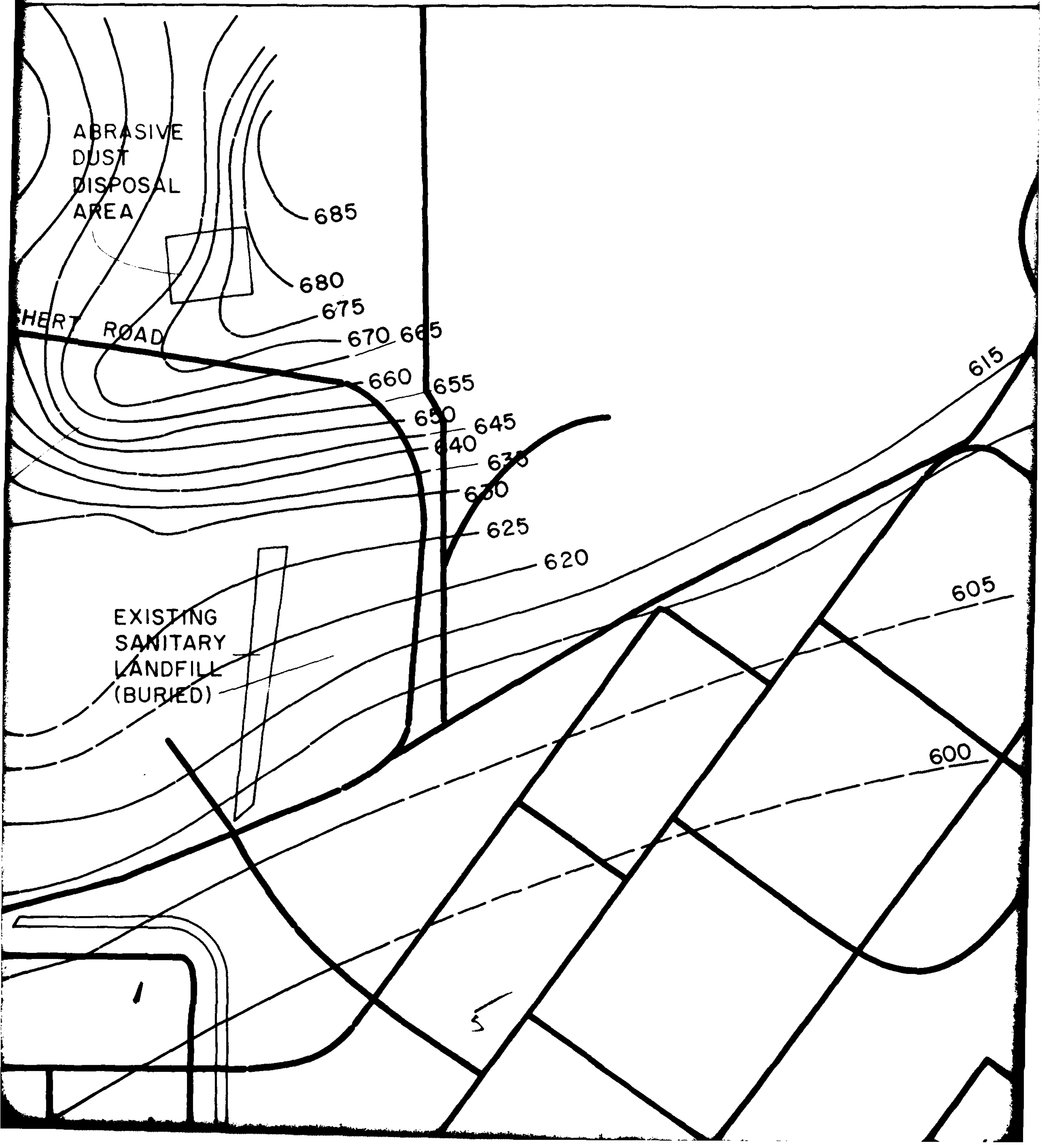
TOPOGRAPHIC CONTOUR (50 FOOT INTERVAL)
AND LOCATION OF MONITOR WELLS

TON ARMY DEPOT	TECHNOS INC.
= 300' ANNISTON ALA	MIAMI FLA SEPTEMBER 1981

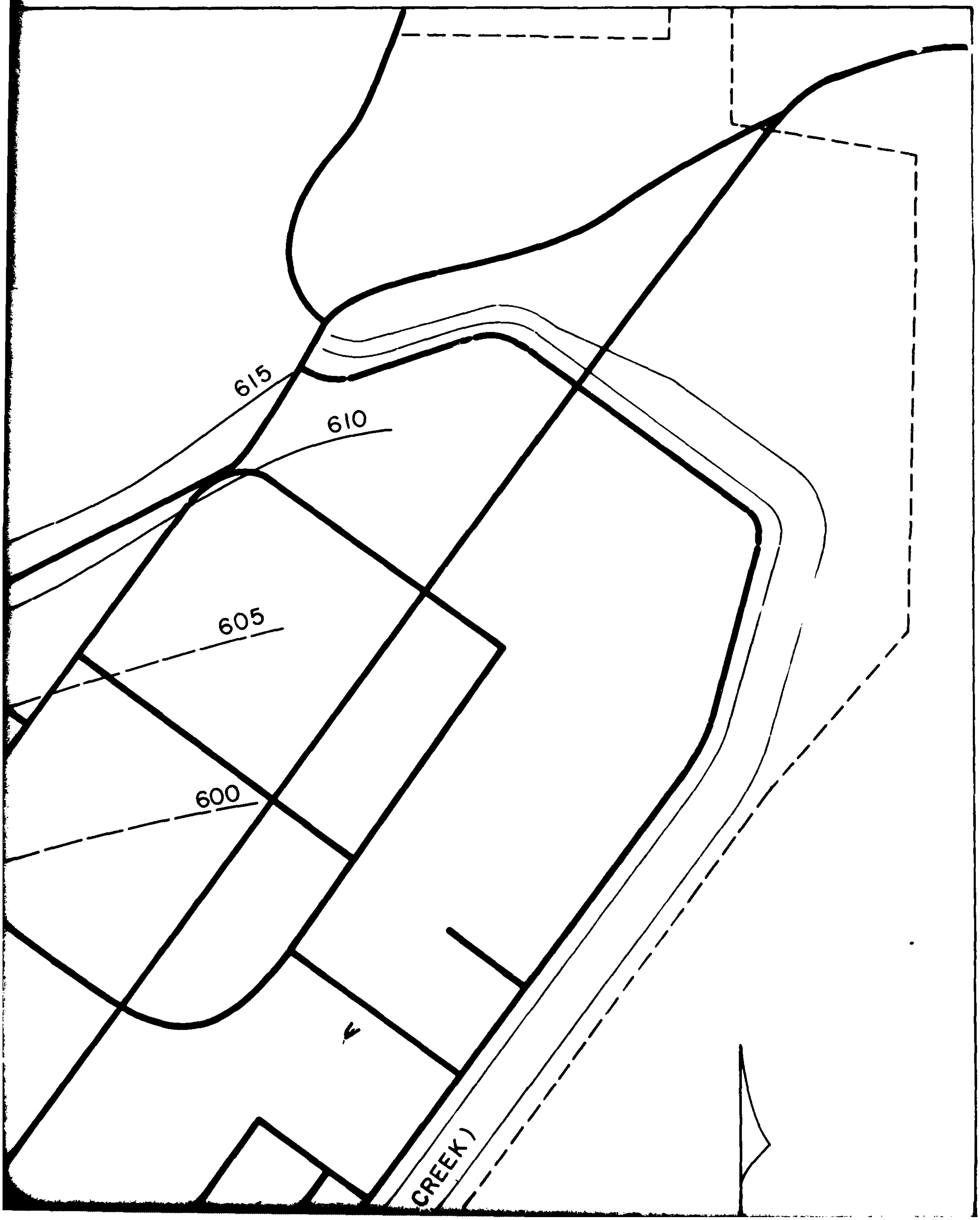
10


CHEMICAL
SLUDGE
TRENCHES
CHERT

1 2


ABRASIVE DUST DISPOSAL AREA
685
680
675
HERT ROAD
670
665
660
655
650
645
640
63
630
625
620
615
605
600
EXISTING SANITARY LANDFILL (BURIED)
5

1 3



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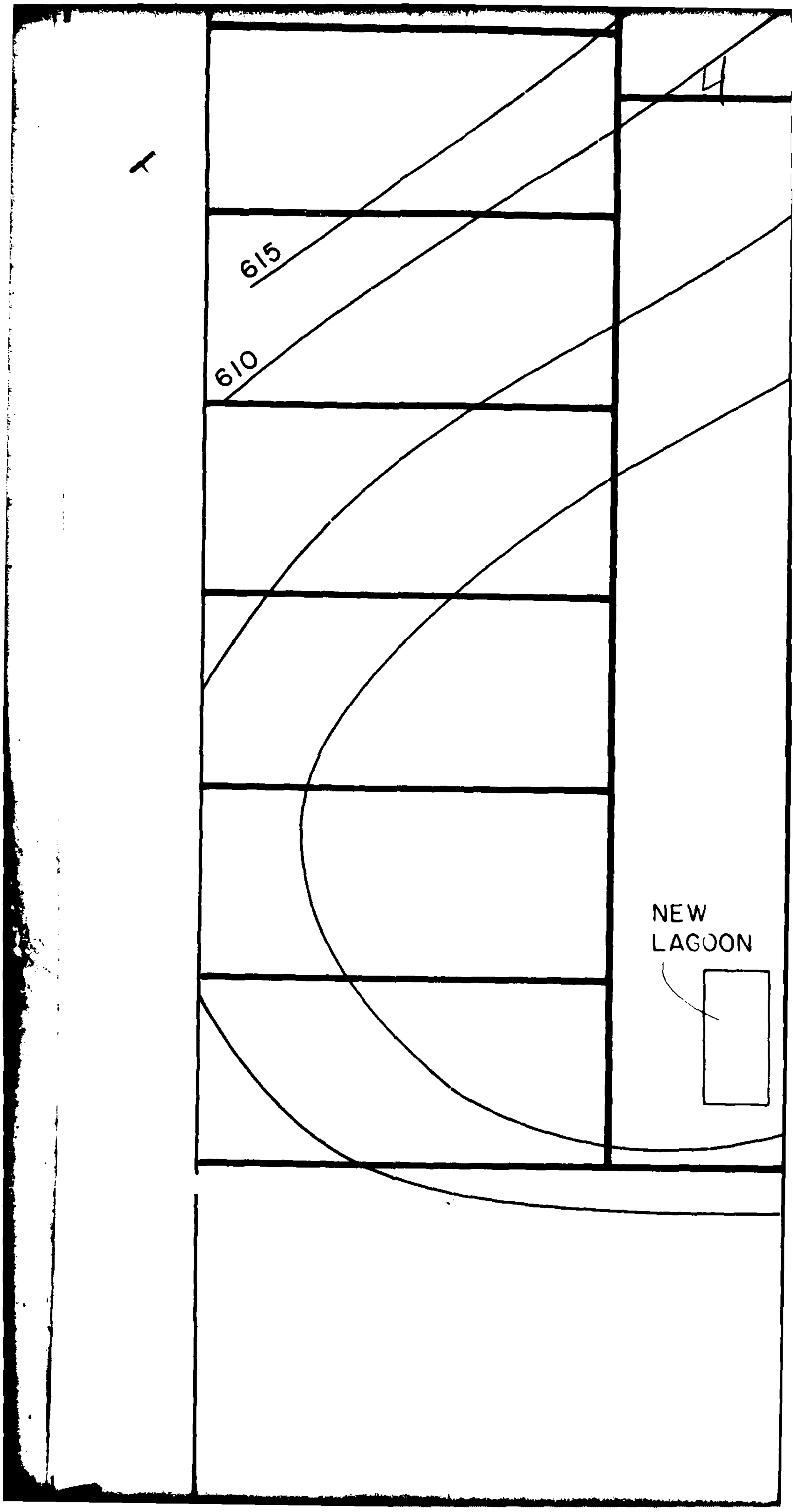
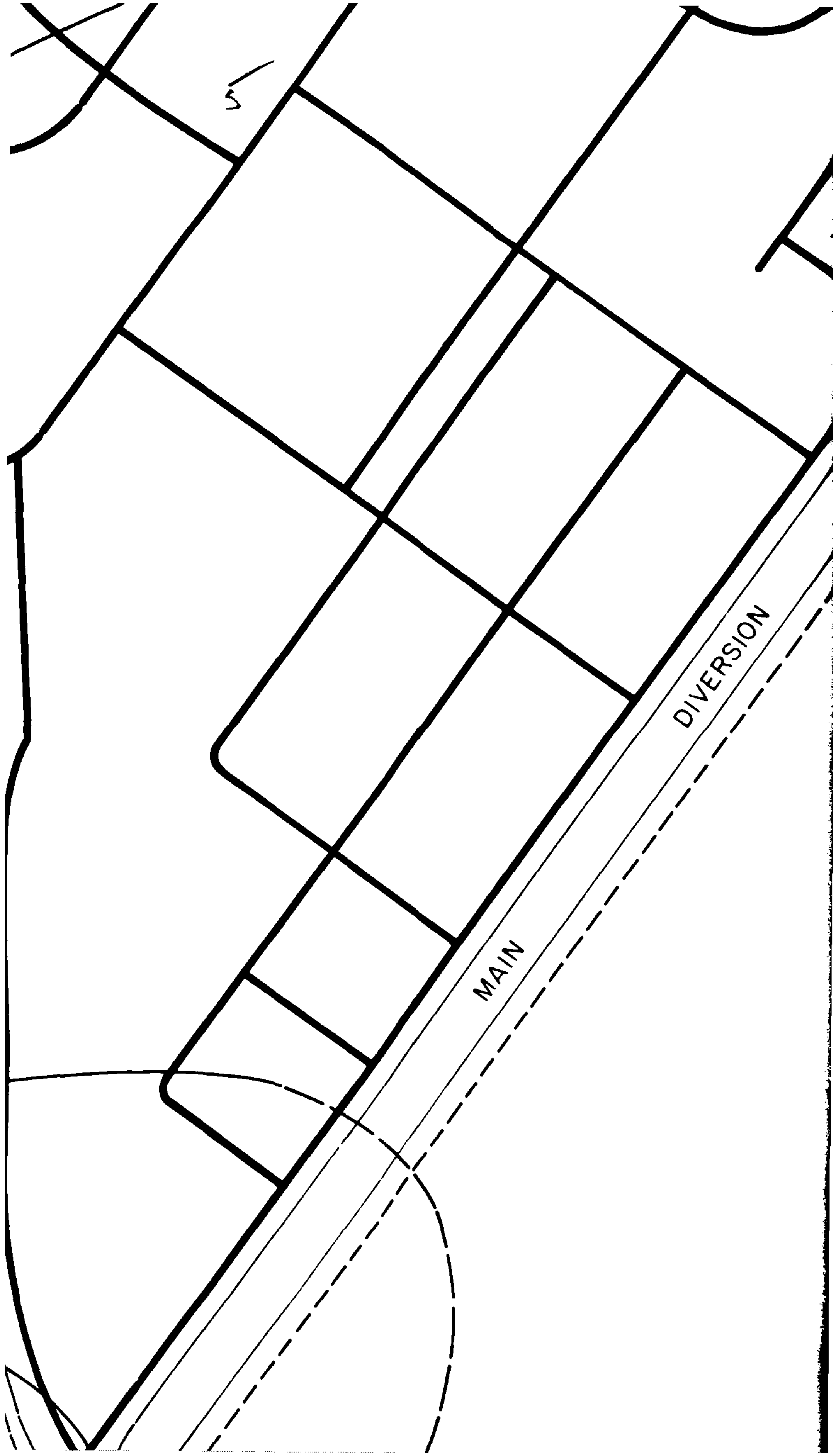
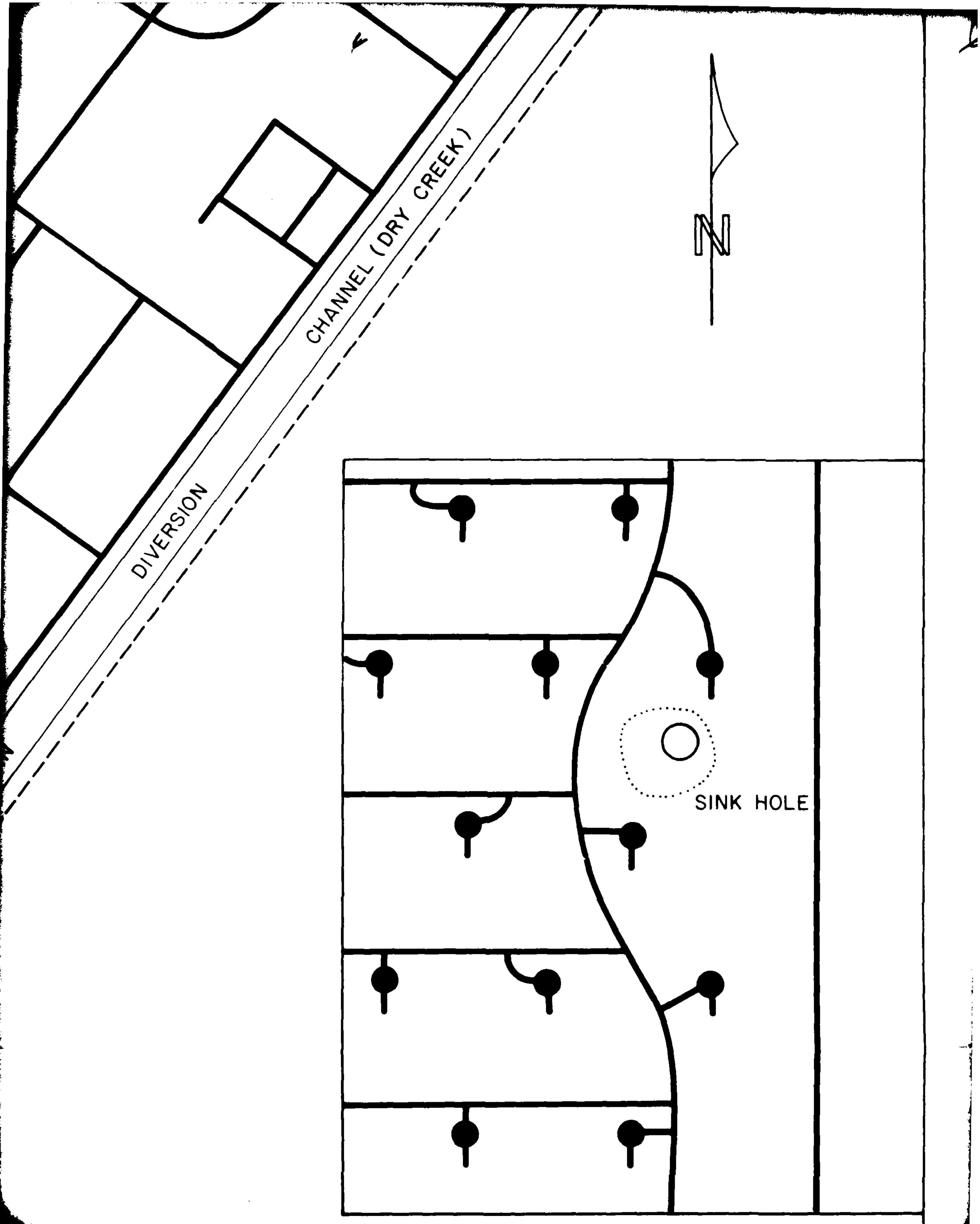
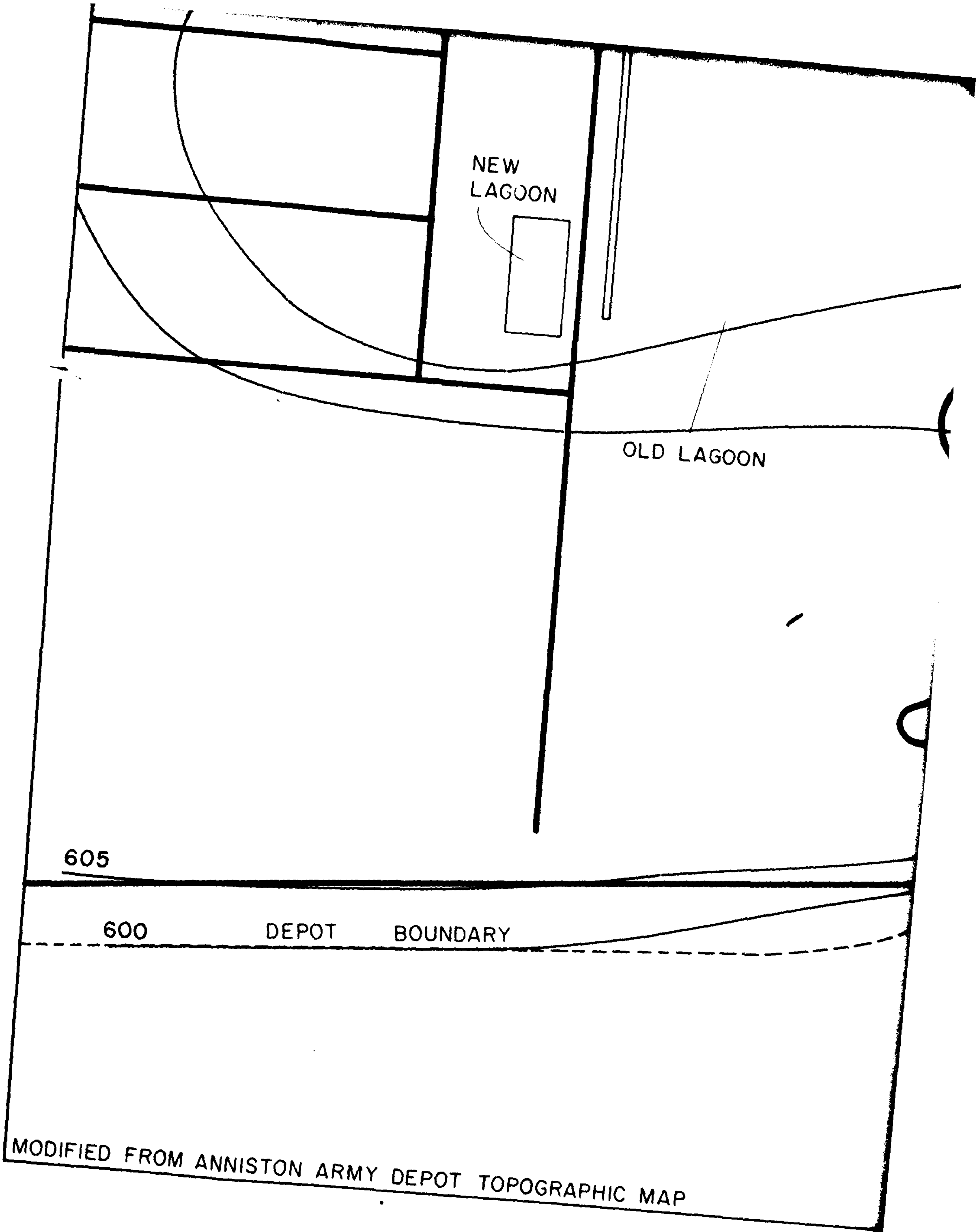

4
615
610
NEW
LAGOON



5
DIVERSION
MAIN



(INSET SHOWING NORTHERN SINKHOLE AREA)


NEW
LAGOON
OLD LAGOON
605
600
DEPOT BOUNDARY
MODIFIED FROM ANNISTON ARMY DEPOT TOPOGRAPHIC MAP

7

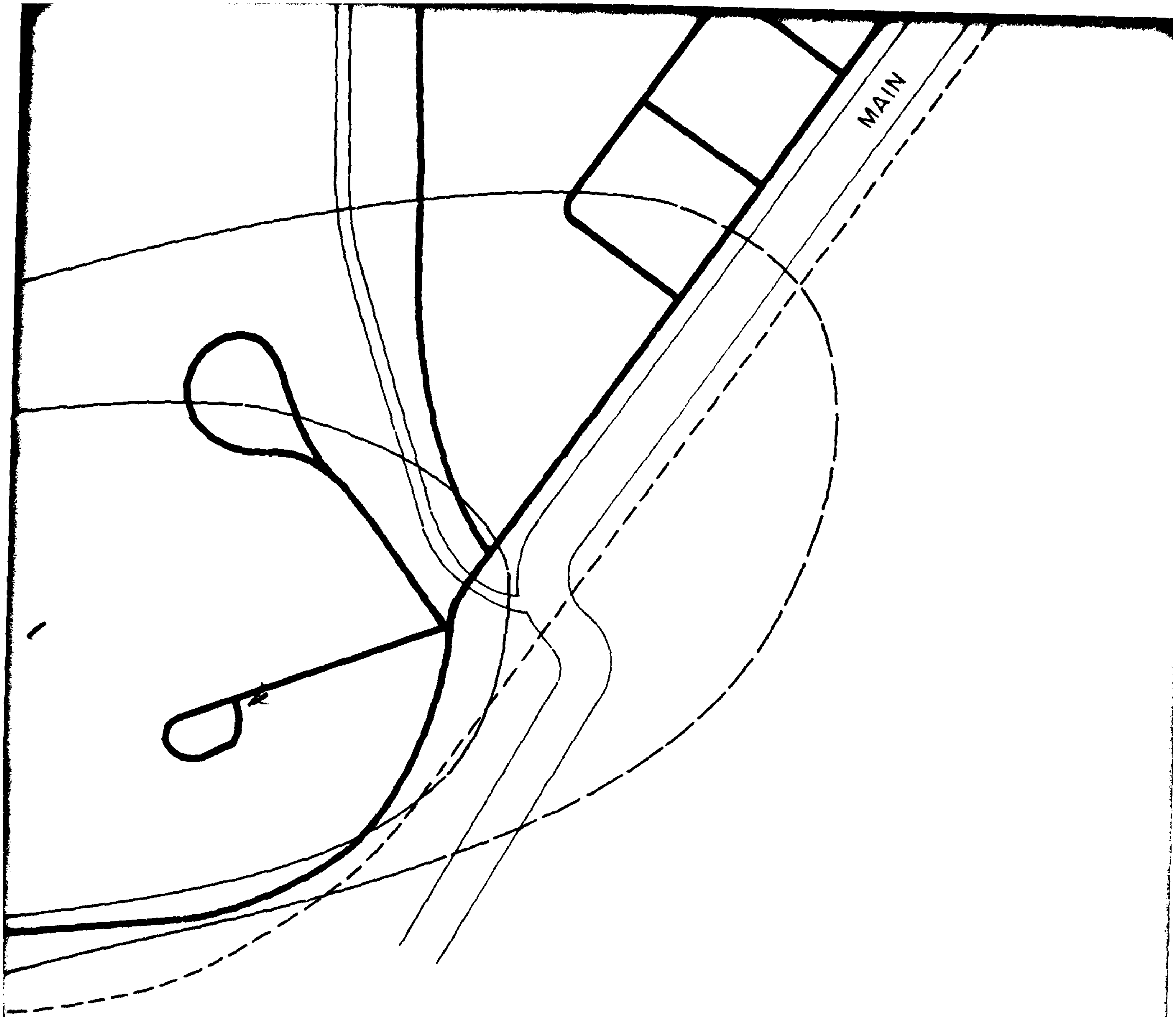
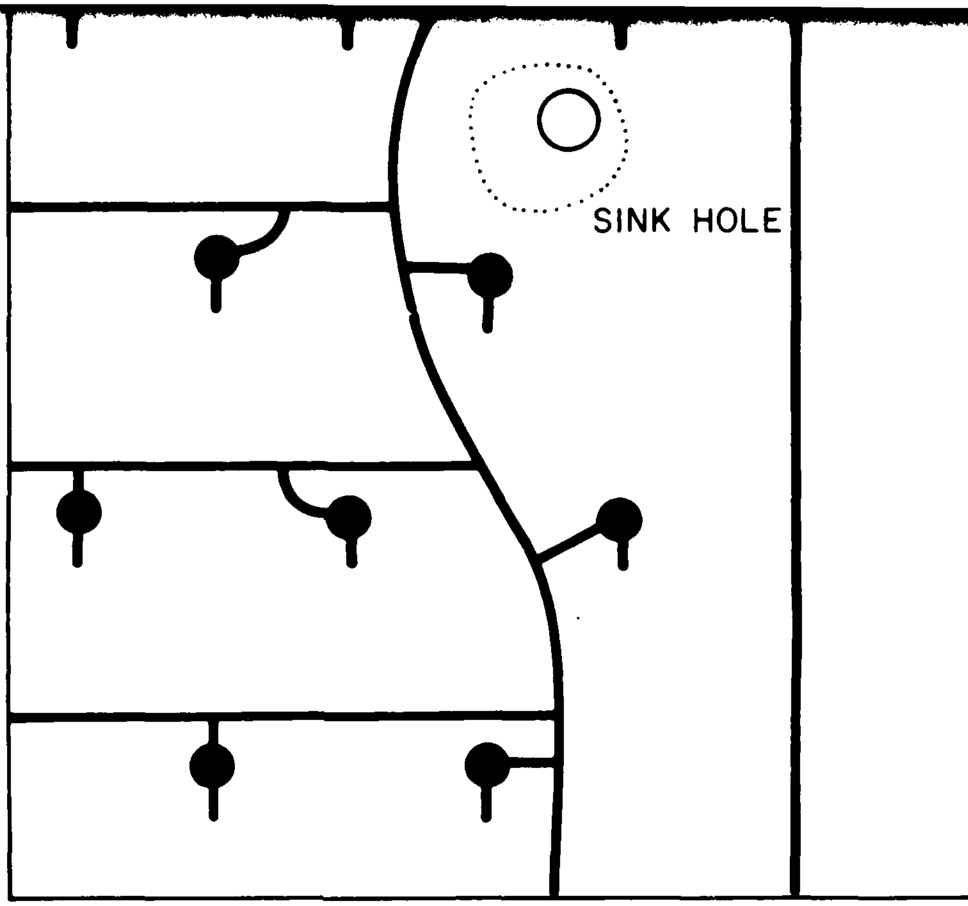


PLATE 5 WAT
MEA

ANNISTON ARMY

SCALE 1" = 300' AN

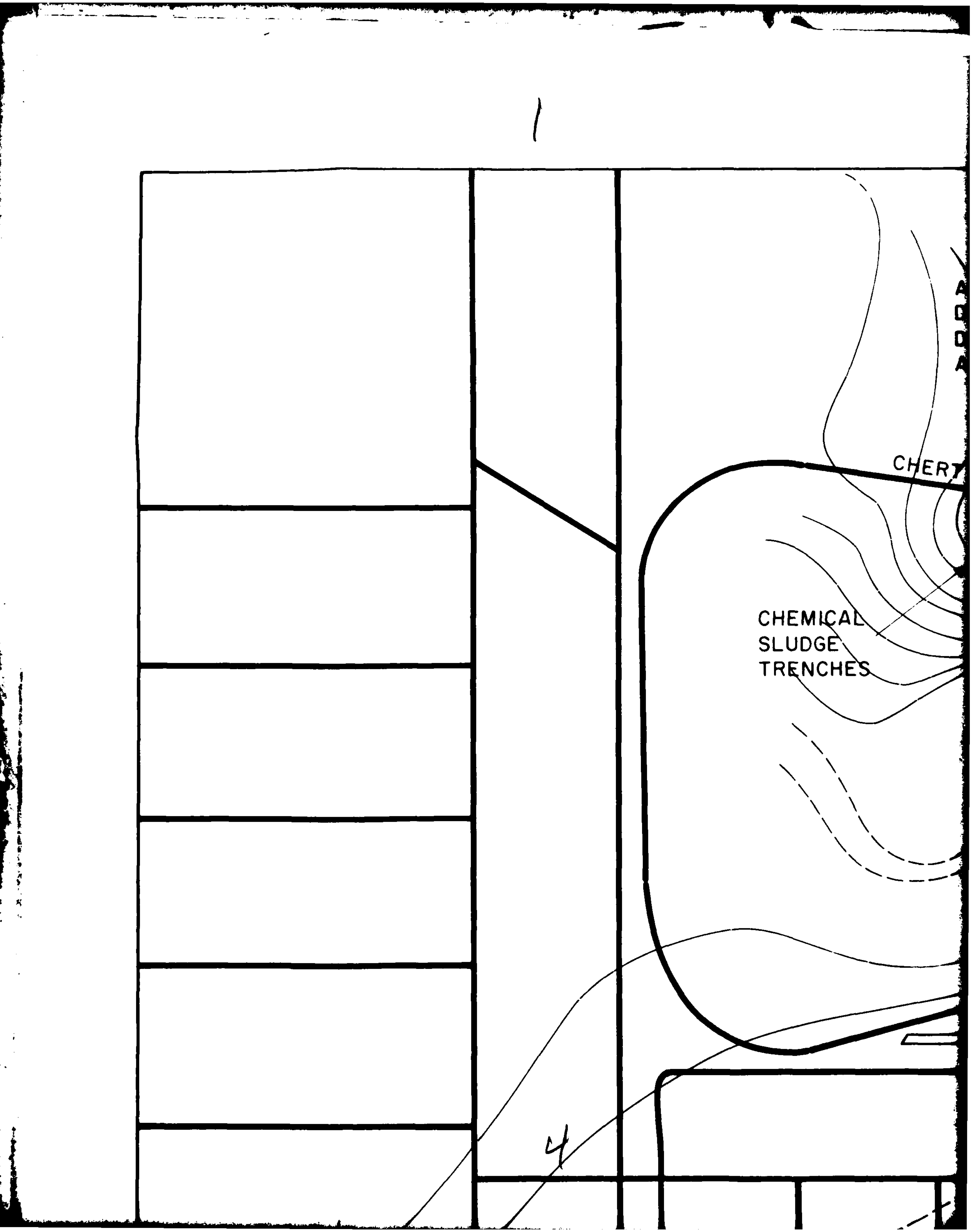


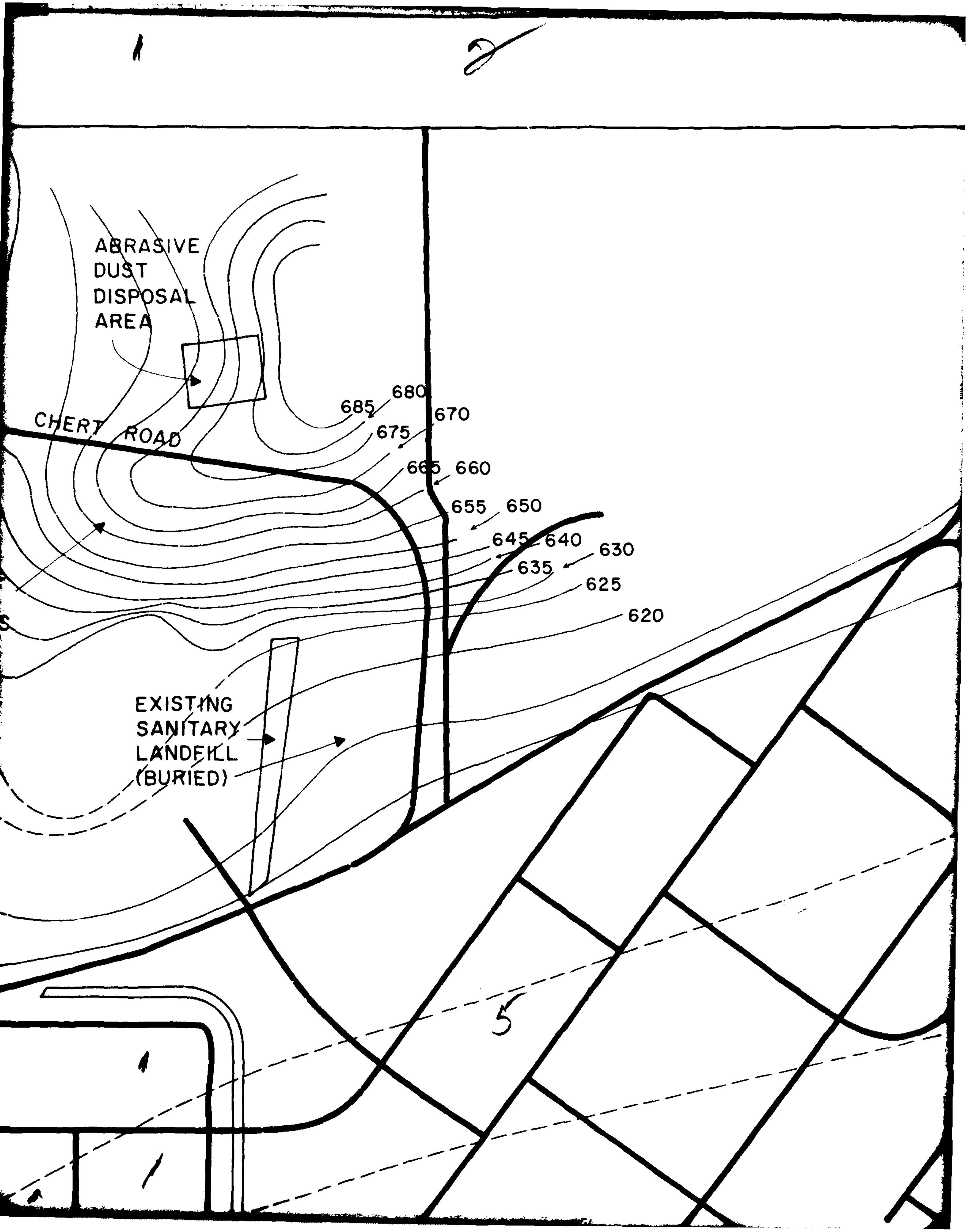
(INSET SHOWING NORTHERN SINKHOLE AREA)

WATER LEVEL CONTOURS (5 FOOT INTERVAL)
MEASUREMENTS TAKEN AUGUST 25, 1981

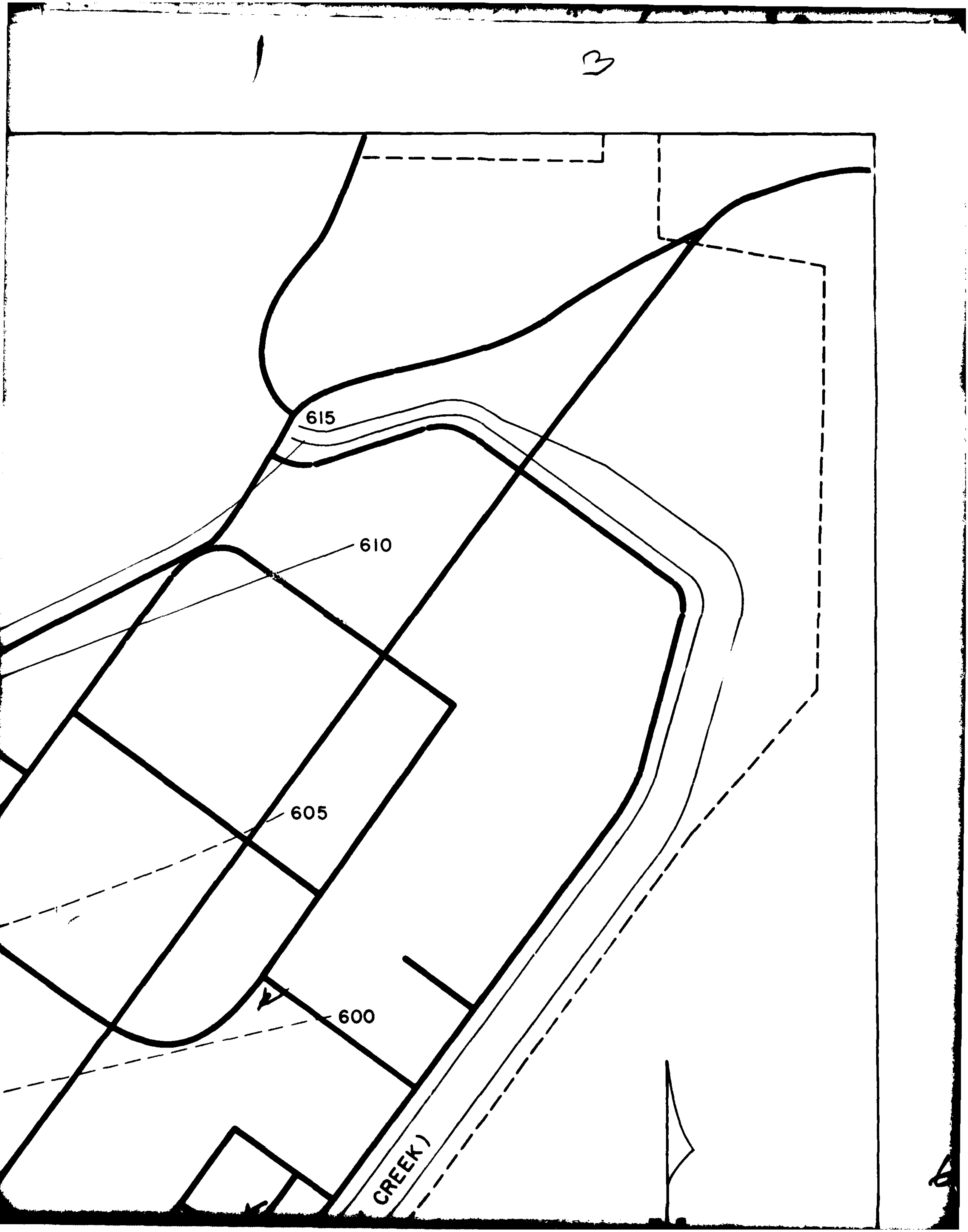
TON ARMY DEPOT	TECHNOS INC.
= 300' ANNISTON ALA	MIAMI FLA SEPTEMBER 1981

9

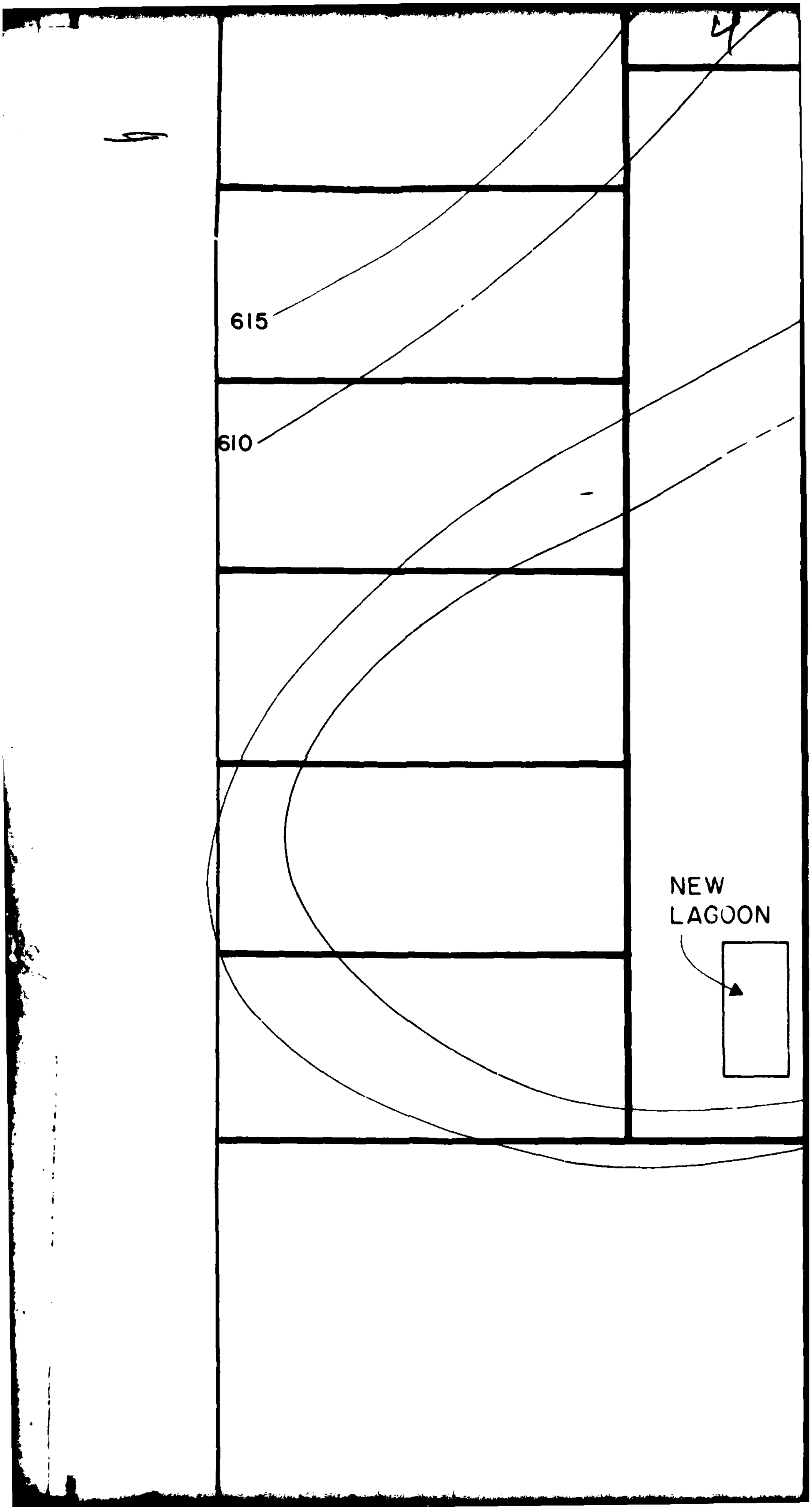

1
CHERT
CHEMICAL
SLUDGE
TRENCHES
4



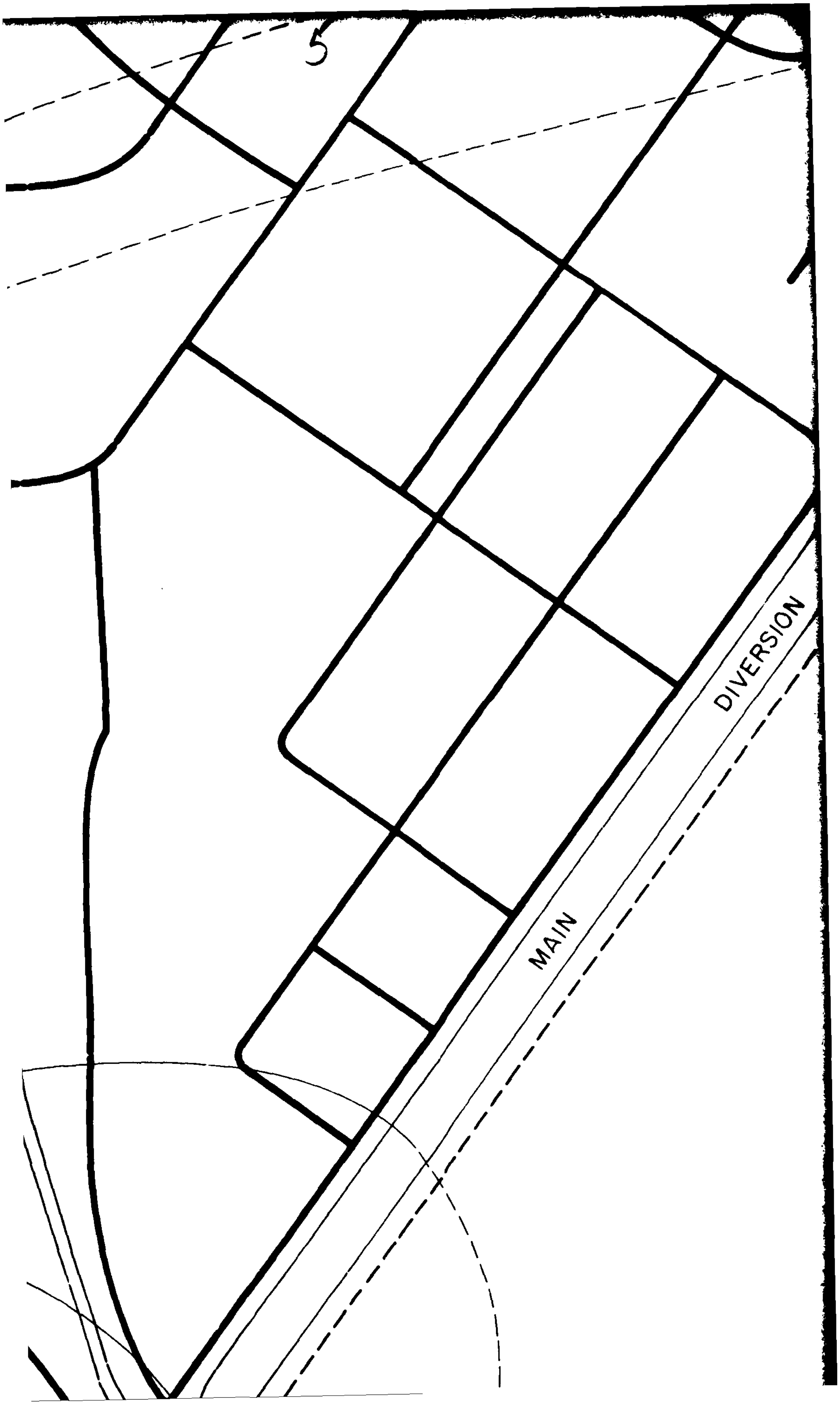
ABRASIVE
DUST
DISPOSAL
AREA
CHERT ROAD
685
680
670
675
665
660
655
650
645
640
630
635
625
620
EXISTING
SANITARY
LANDFILL
(BURIED)

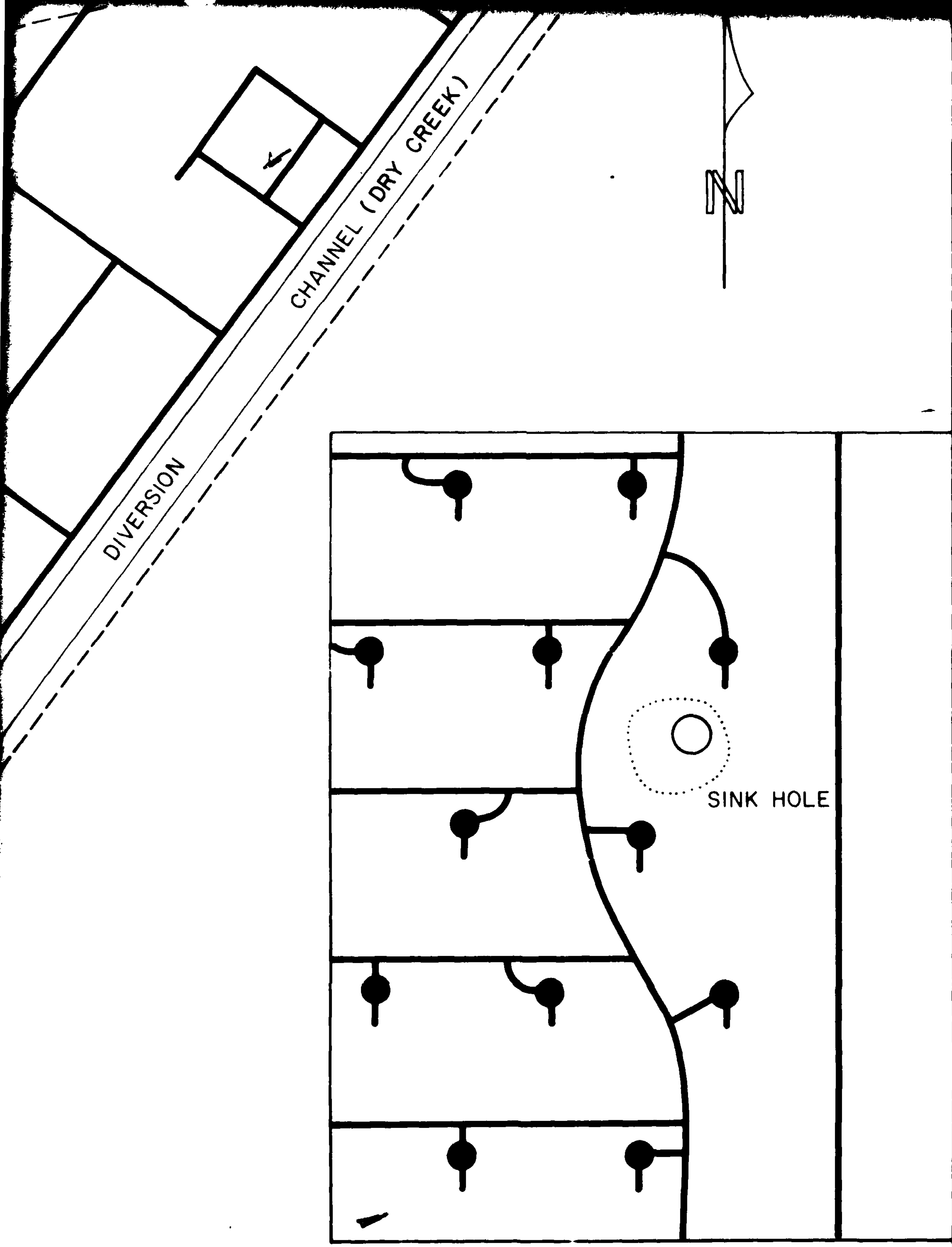


1
3
615
610
605
600
CREEK)

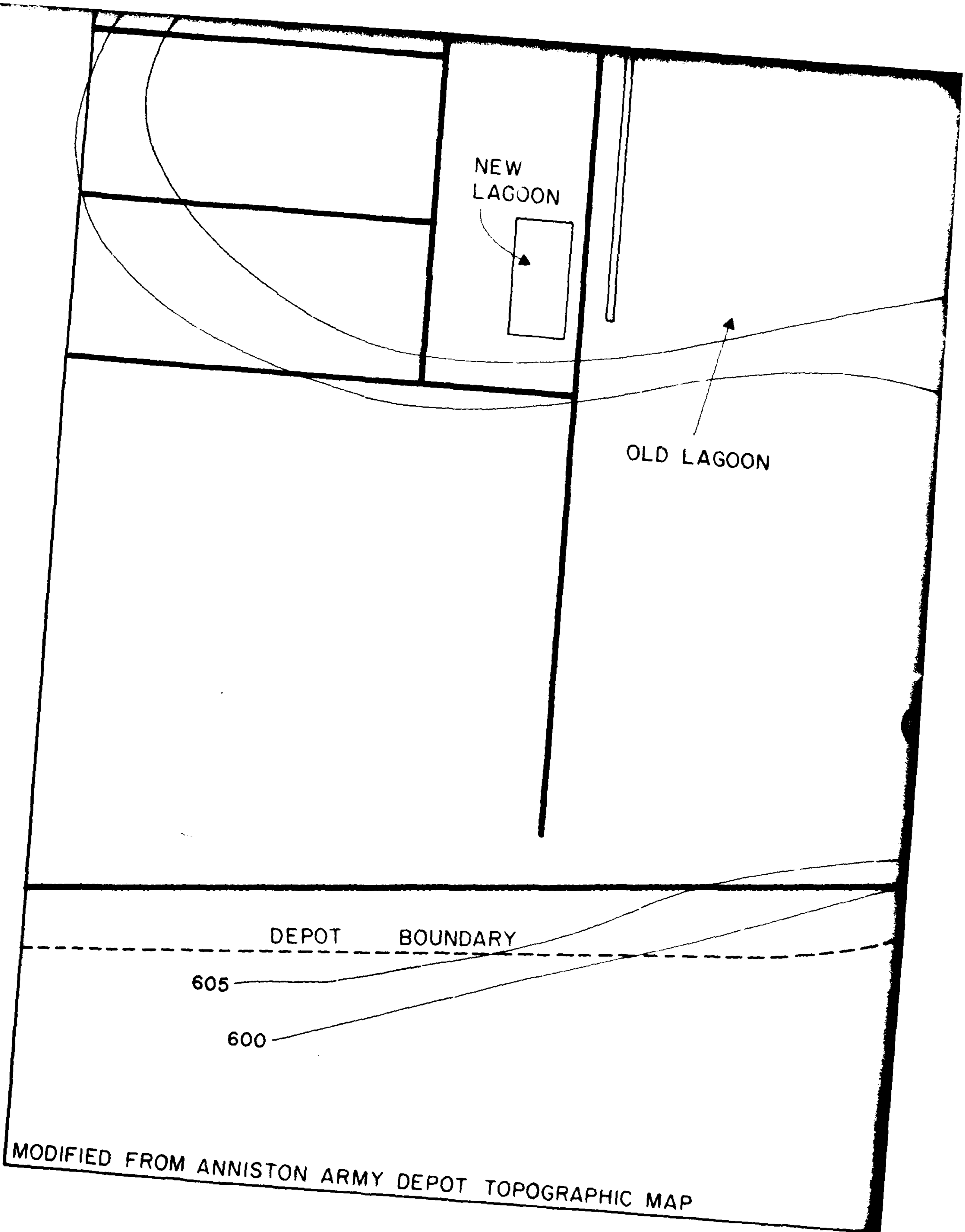


4
615
610
NEW
LAGOON


5
MAIN
DIVERSION



(INSET SHOWING NORTHERN SINKHOLE AREA)


NEW
LAGOON
OLD LAGOON
DEPOT BOUNDARY
605
600
MODIFIED FROM ANNISTON ARMY DEPOT TOPOGRAPHIC MAP

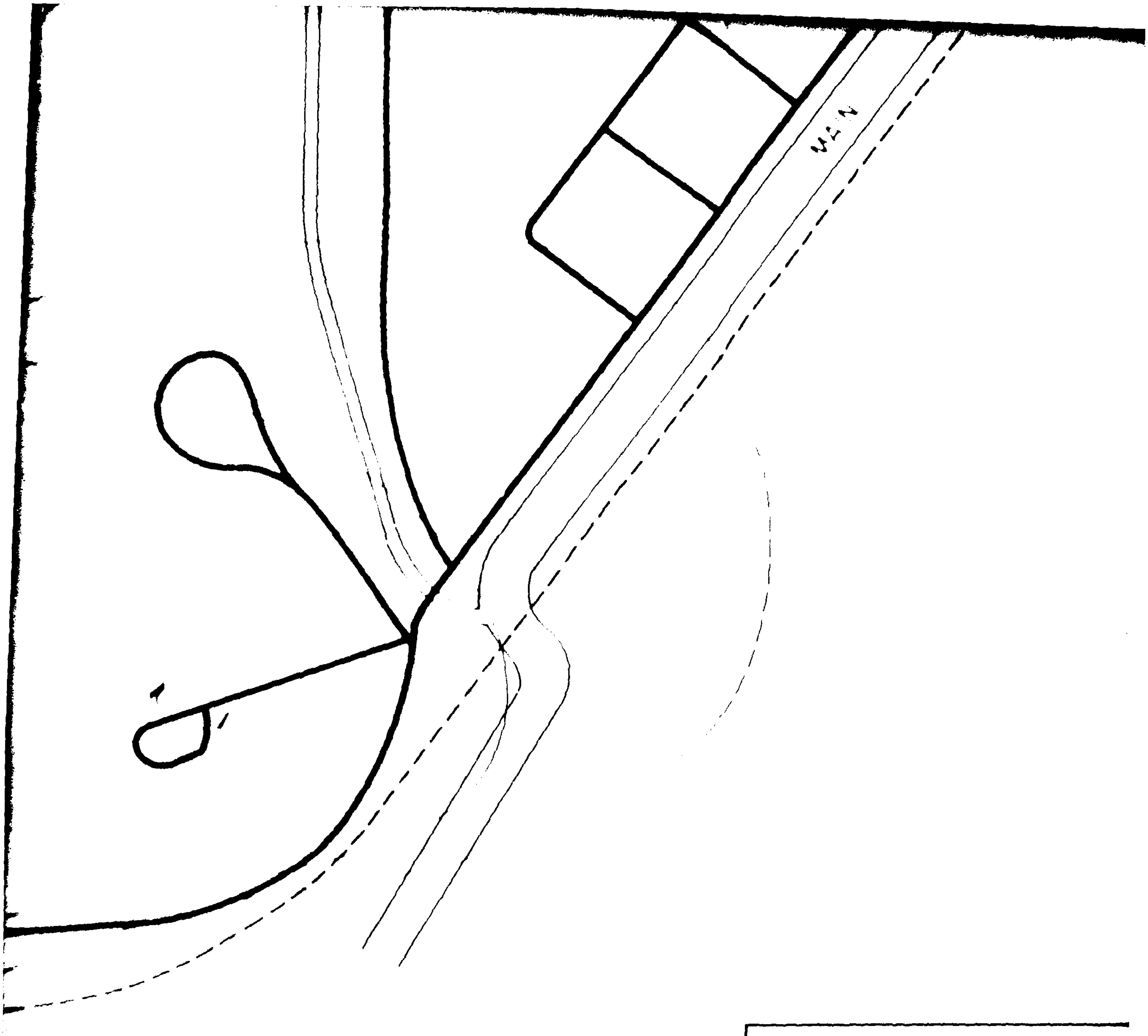
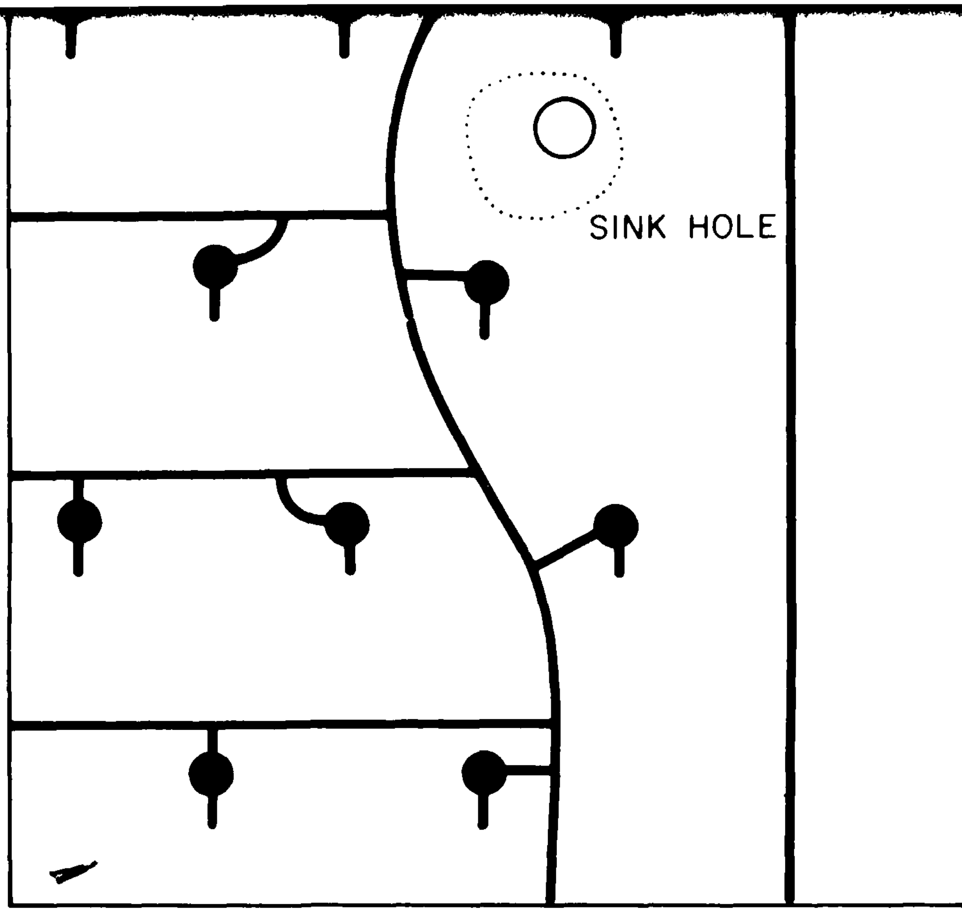


PLATE 4 WATER
MEASU

ANNISTON ARMY

SCALE 1" = 300' ANNI

8



(INSET SHOWING NORTHERN SINKHOLE AREA)

4 WATER LEVEL CONTOURS (5 FOOT INTERVAL)

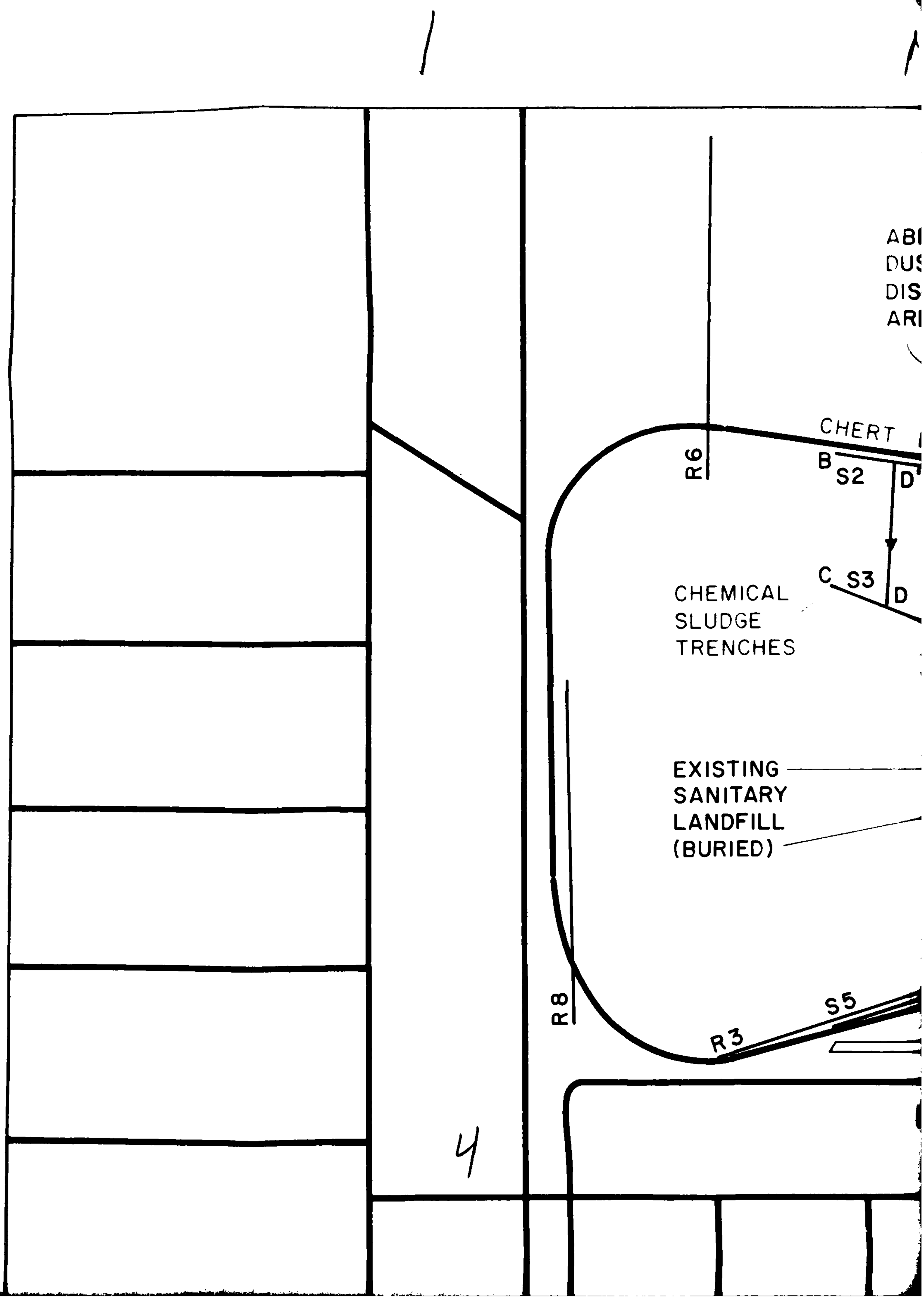
MEASUREMENTS TAKEN JULY 24, 1981

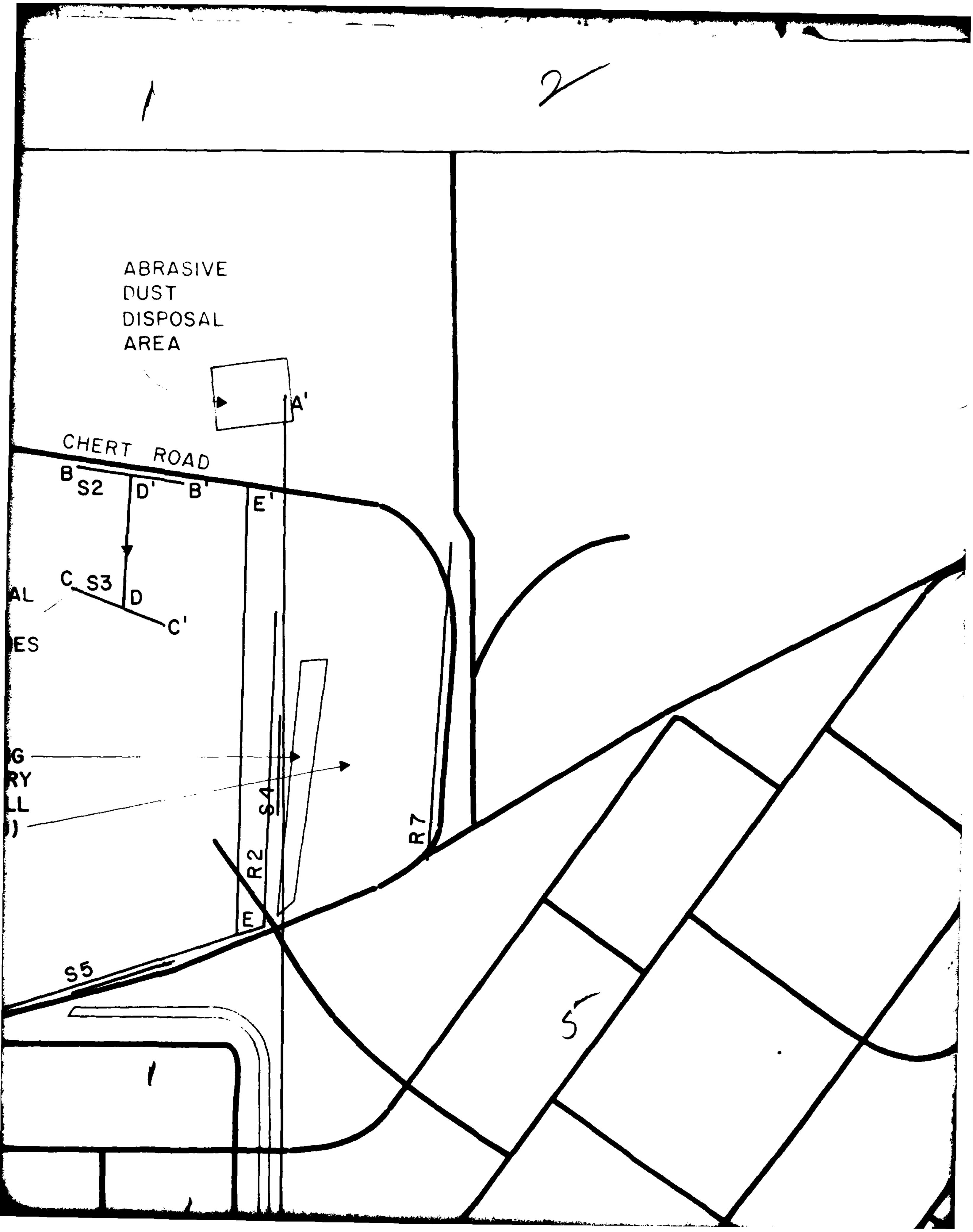
TON ARMY DEPOT

" = 300' ANNISTON ALA

TECHNOS INC.

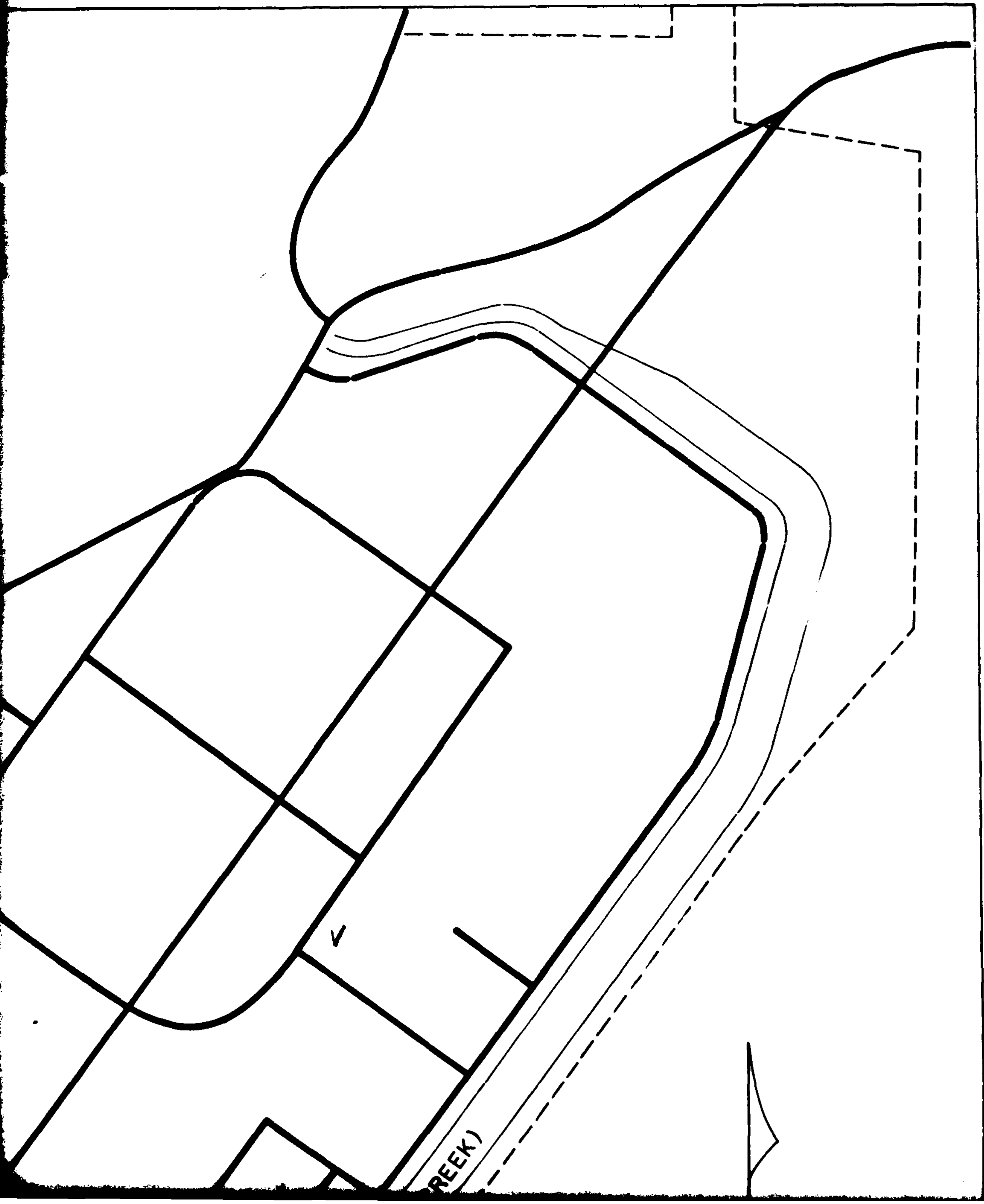
MIAMI FLA SEPTEMBER 1981


1
CHERT
B
S2
D
C
S3
D
R6
CHEMICAL
SLUDGE
TRENCHES
EXISTING
SANITARY
LANDFILL
(BURIED)
R8
R3
S5
4

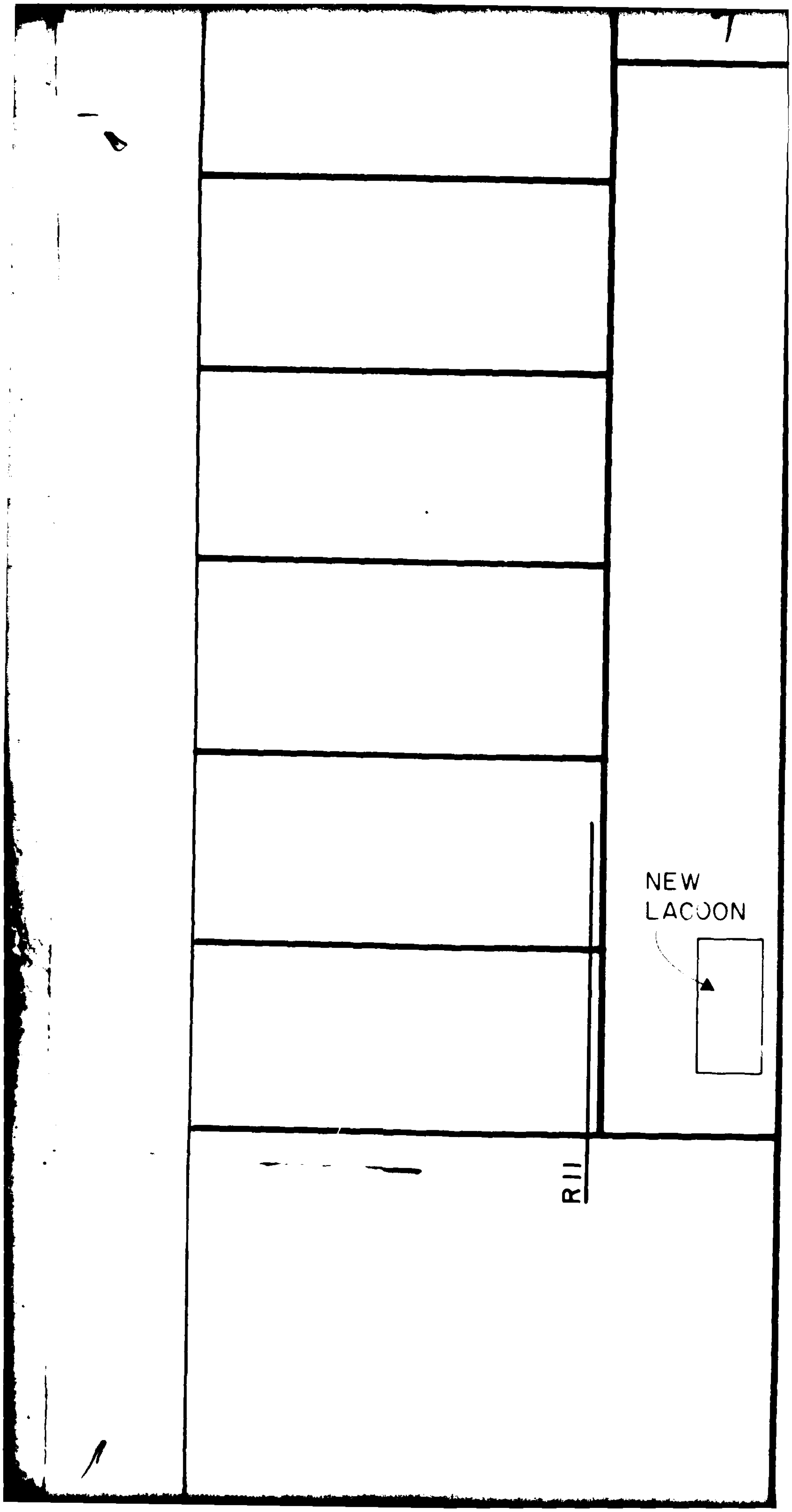

1
2
ABRASIVE
DUST
DISPOSAL
AREA
A'
CHERT ROAD
B
S2
D'
B'
E'
C
S3
D
C'
AL
ES
G
RY
LL
S4
R7
R2
E
S5
5
1

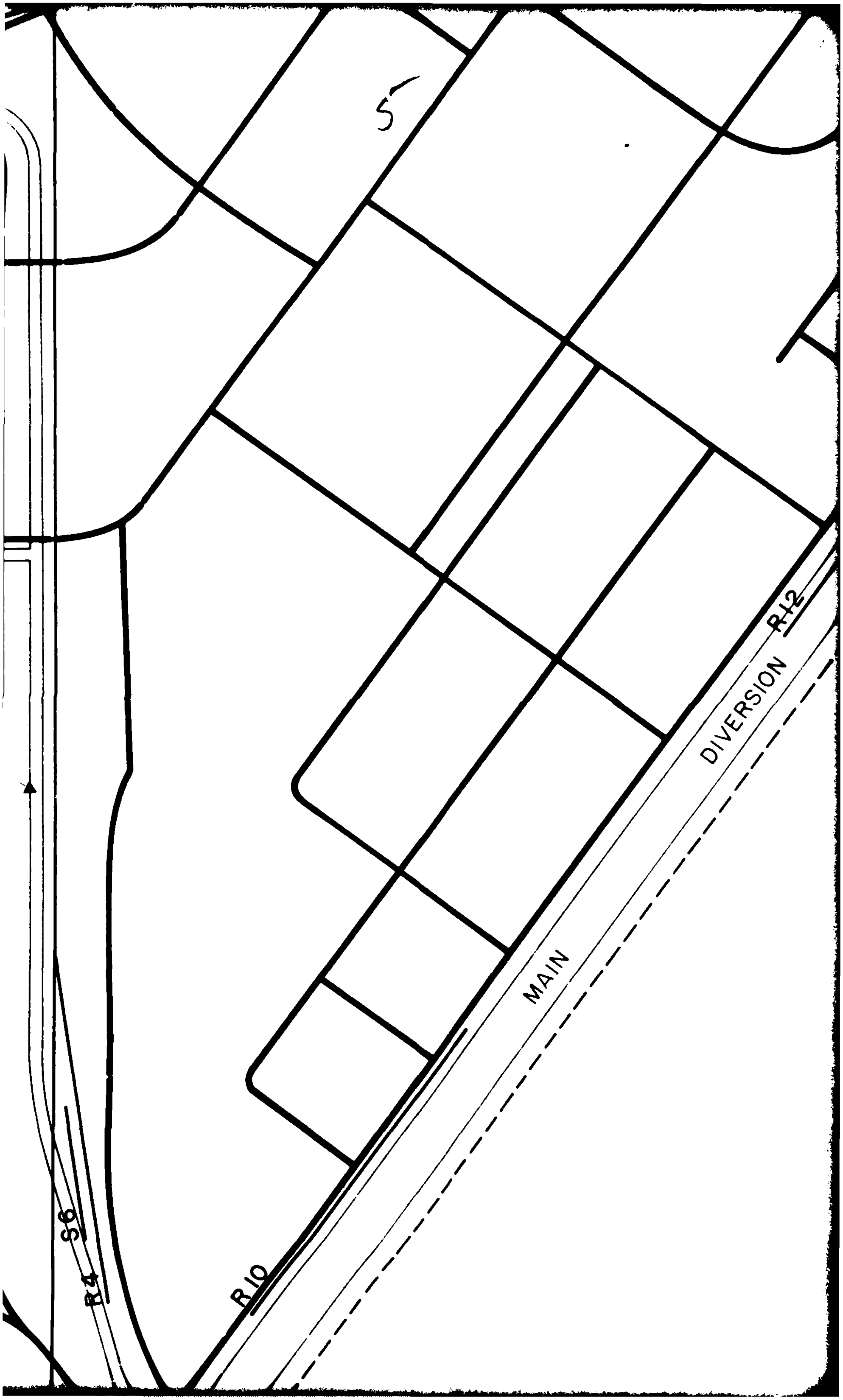
1

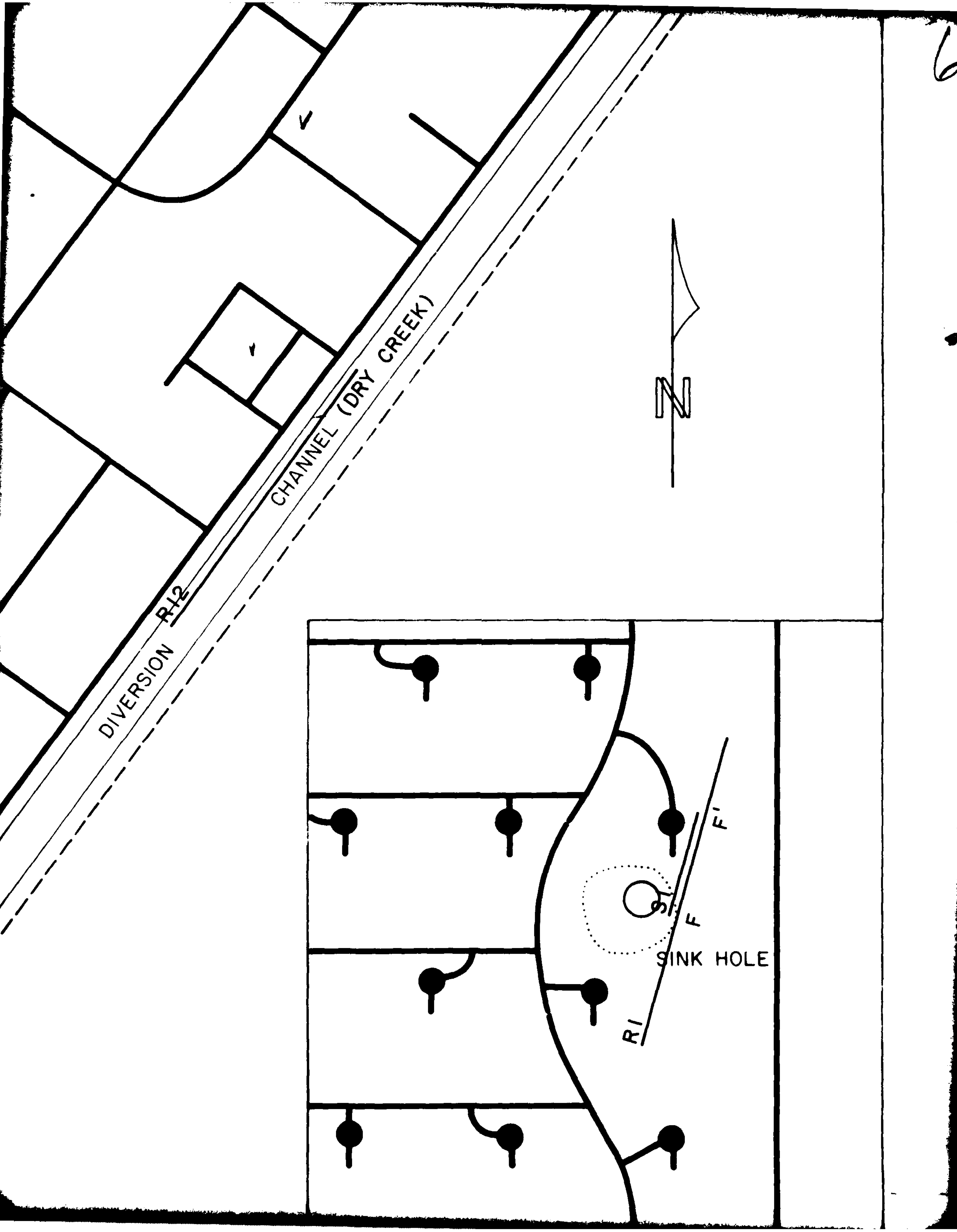
3

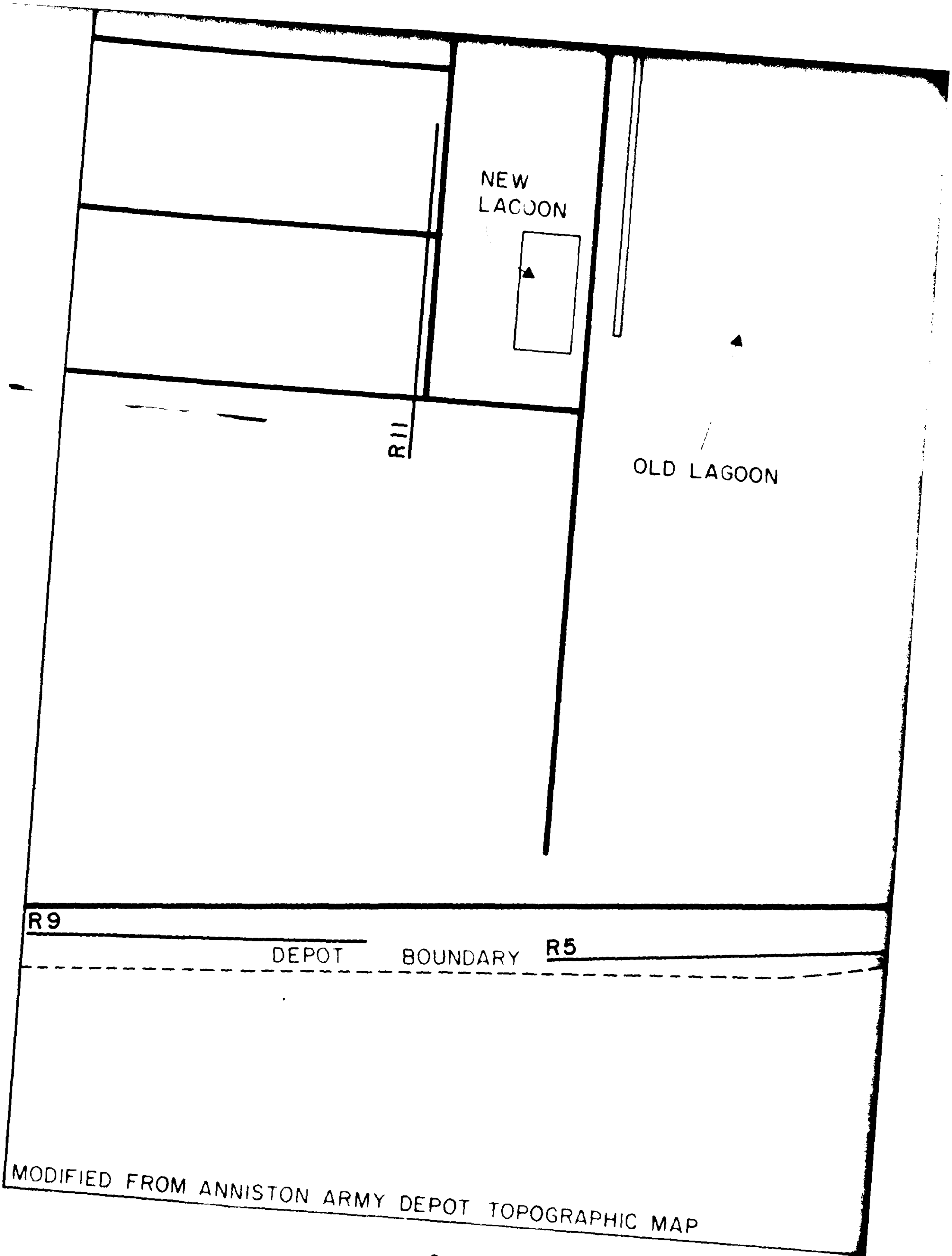


6


NEW
LAGOON
R11


5
S6
R4
RIO
MAIN
DIVERSION
R12


6
DIVERSION CHANNEL (DRY CREEK)
R12
N
F'
F
SINK HOLE
RI


NEW
LAGOON
R11
OLD LAGOON
R9
DEPOT BOUNDARY
R5
MODIFIED FROM ANNISTON ARMY DEPOT TOPOGRAPHIC MAP

7

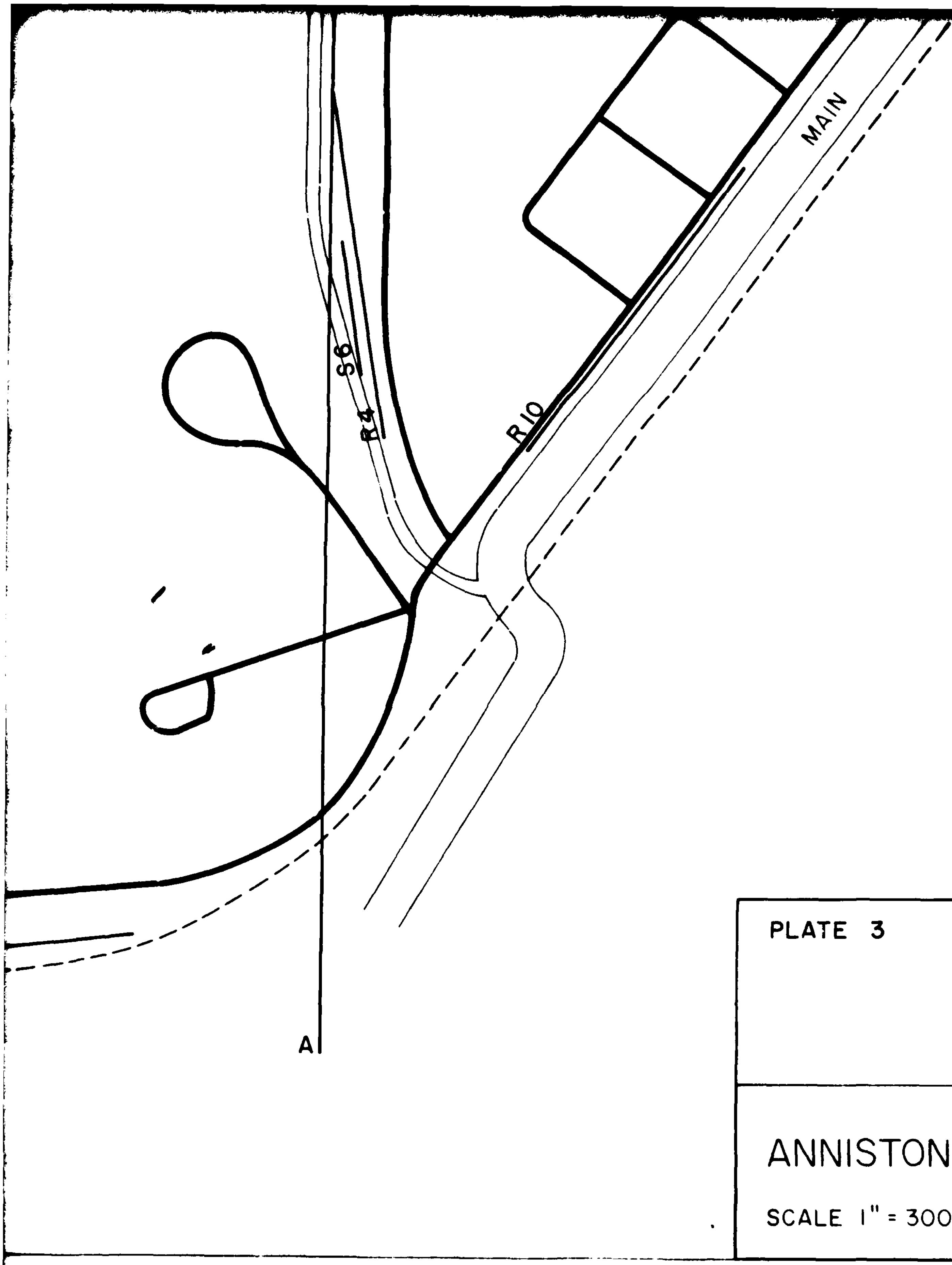
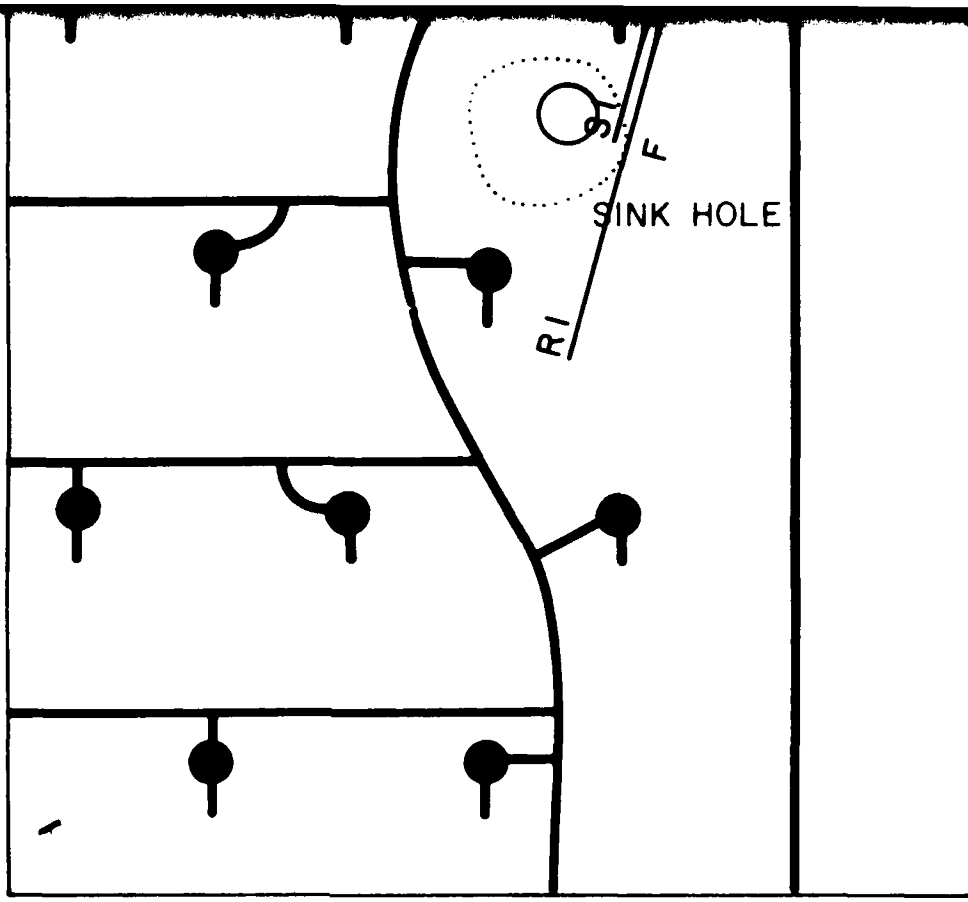


PLATE 3	LOCAT
	RI
	SI
	A

ANNISTON ARMY

SCALE 1" = 300' ANN



(INSET SHOWING NORTHERN SINKHOLE AREA)

LOCATION MAP OF:

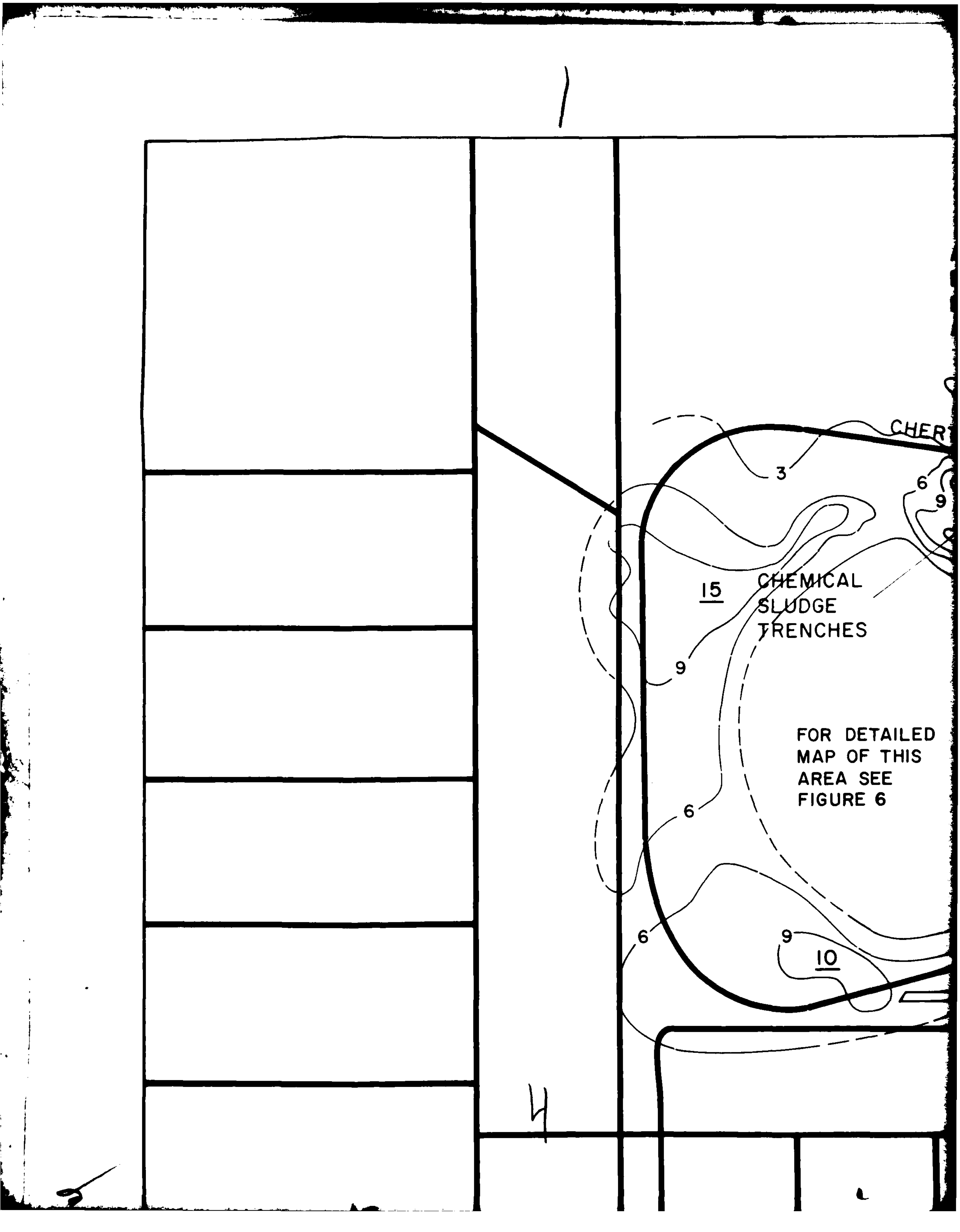
RI ______________ RESISTIVITY SOUNDINGS

SI ______________ SEISMIC REFRACTION LINES

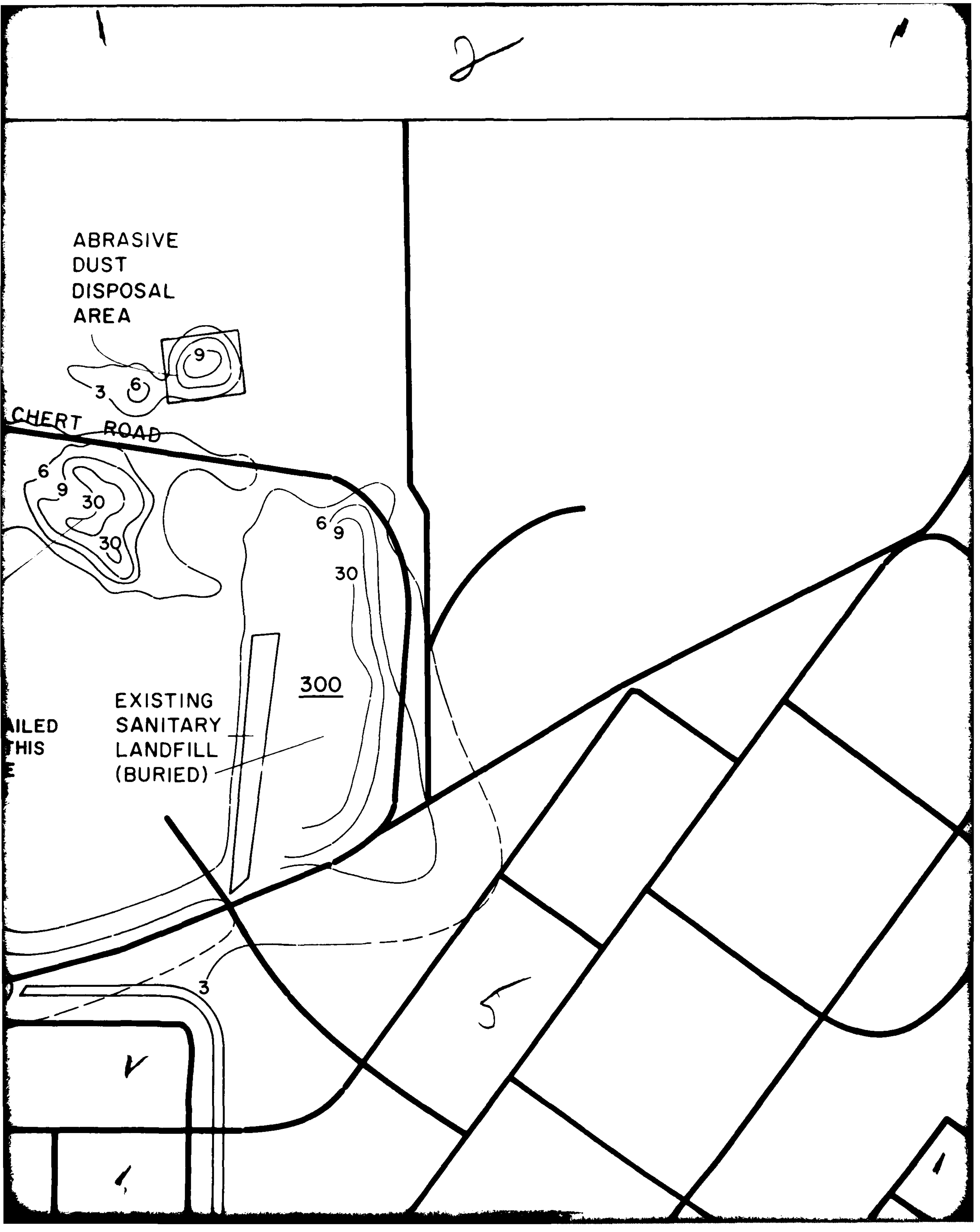
A ______________ A' GEOLOGIC CROSS-SECTIONS

TON ARMY DEPOT	TECHNOS INC.
" = 300' ANNISTON ALA	MIAMI FLA SEPTEMBER 1981

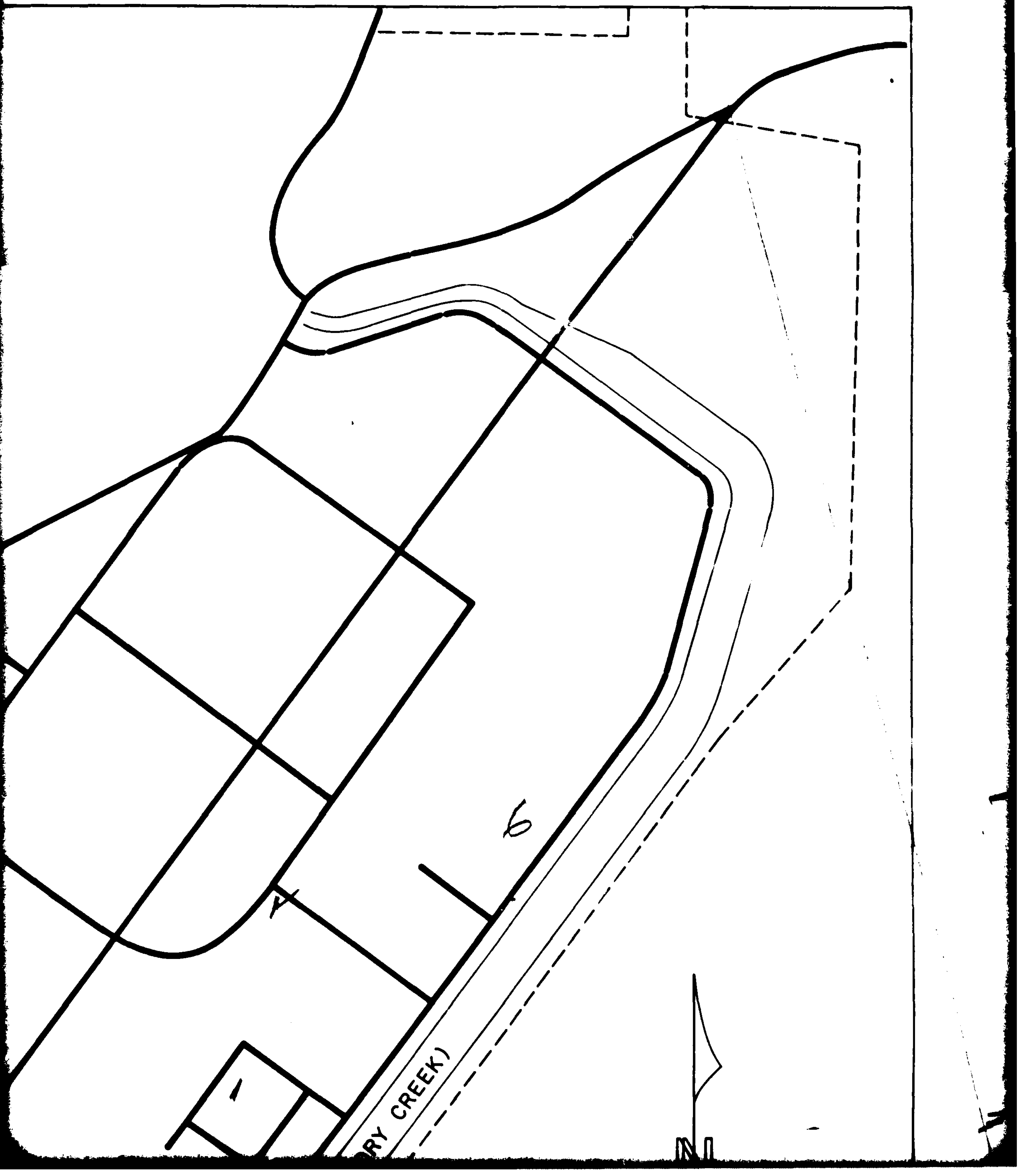
9

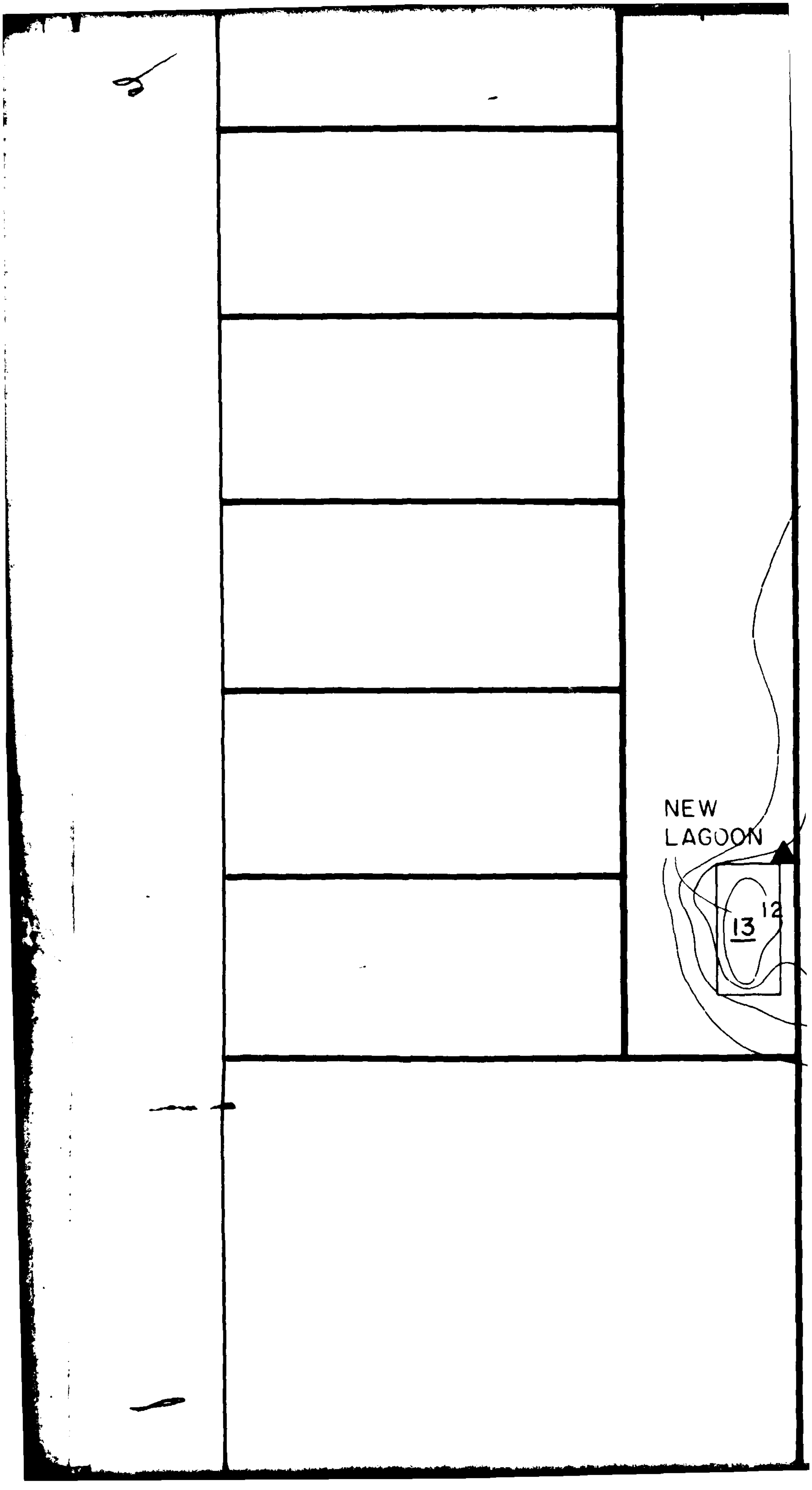


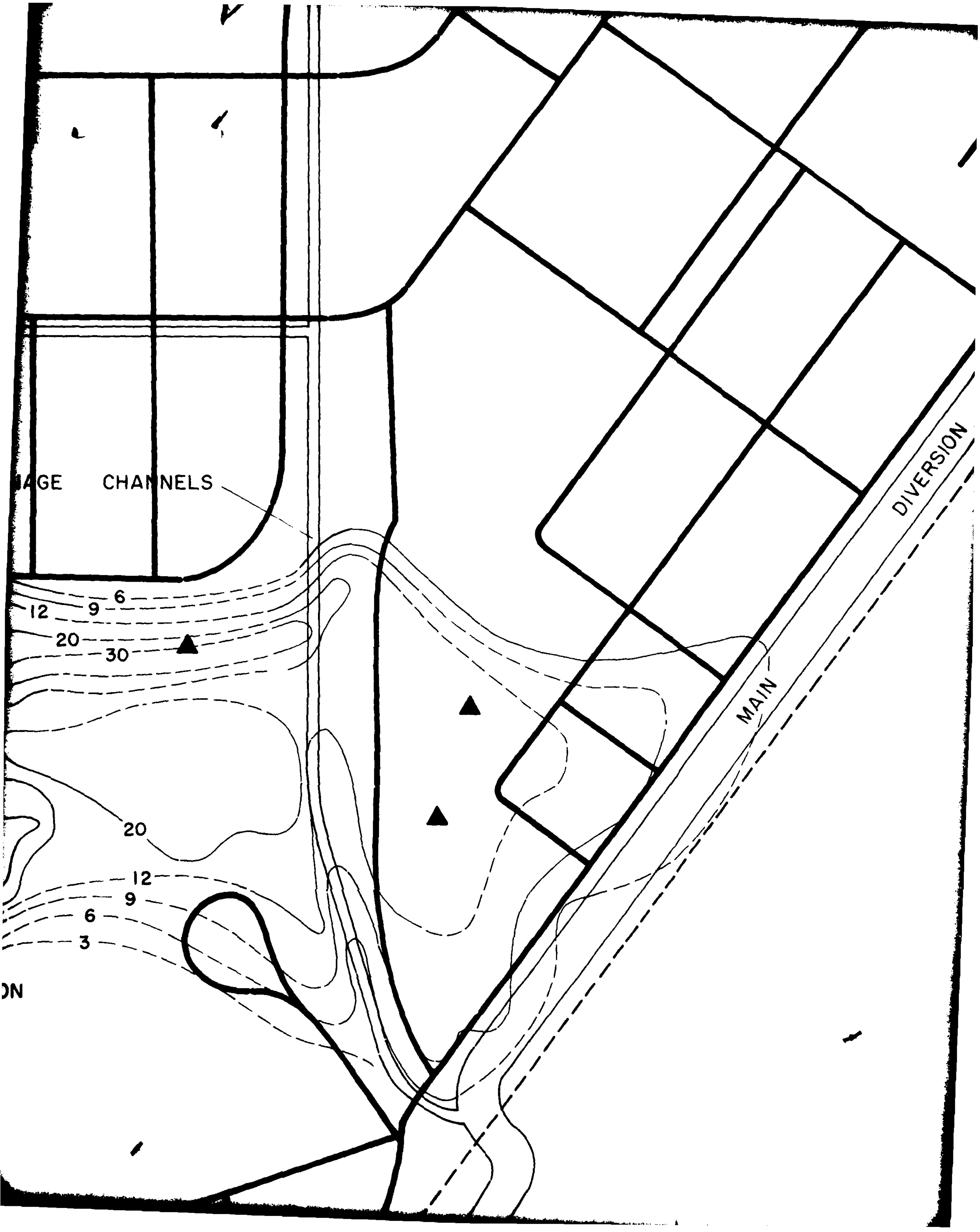
CHER
3
6
9
15
CHEMICAL
SLUDGE
TRENCHES
9
FOR DETAILED
MAP OF THIS
AREA SEE
FIGURE 6
6
6
9
10


ABRASIVE DUST DISPOSAL AREA
9
6
3
CHERT ROAD
6
9
30
30
6
9
30
300
EXISTING SANITARY LANDFILL (BURIED)
3

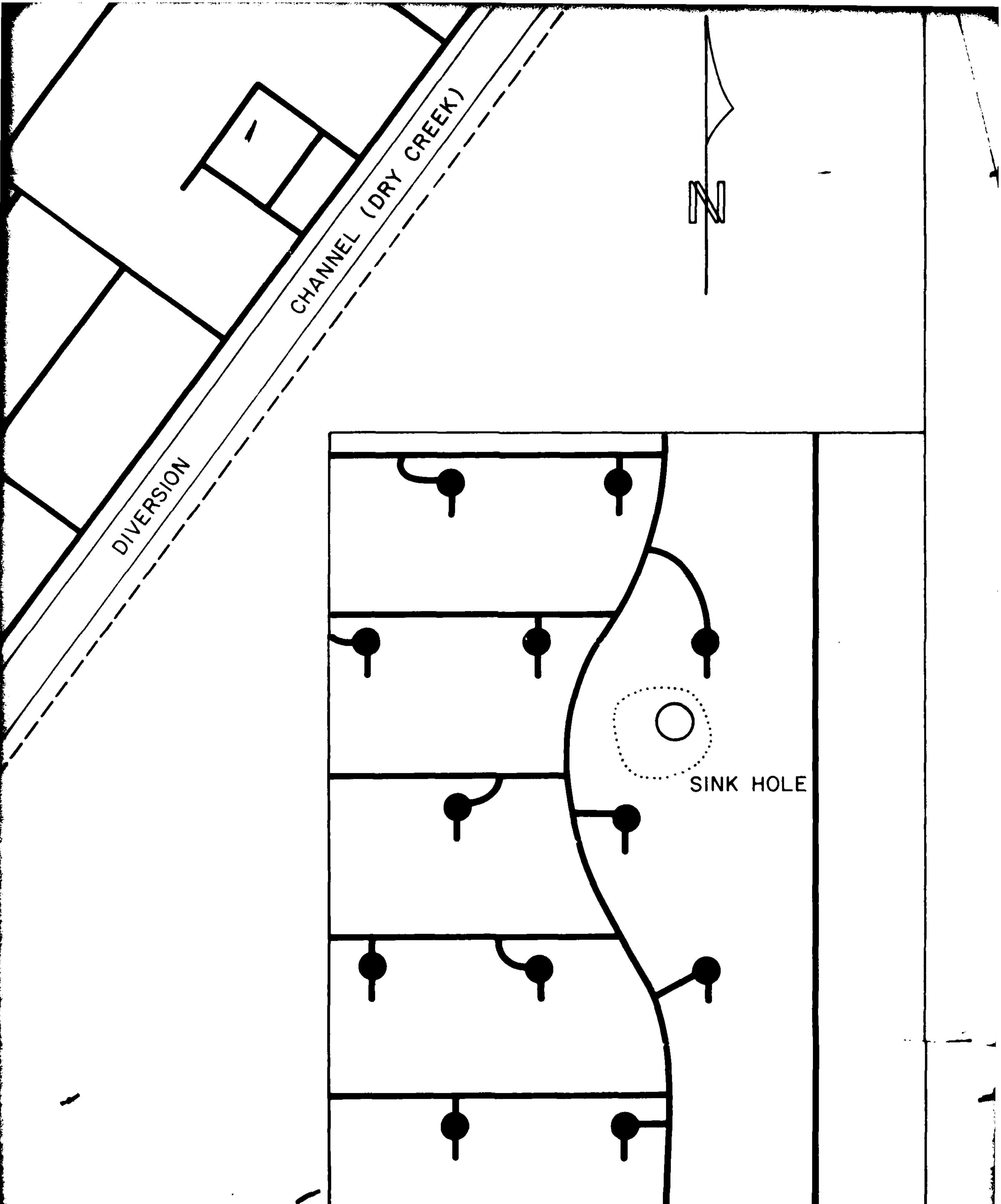
3



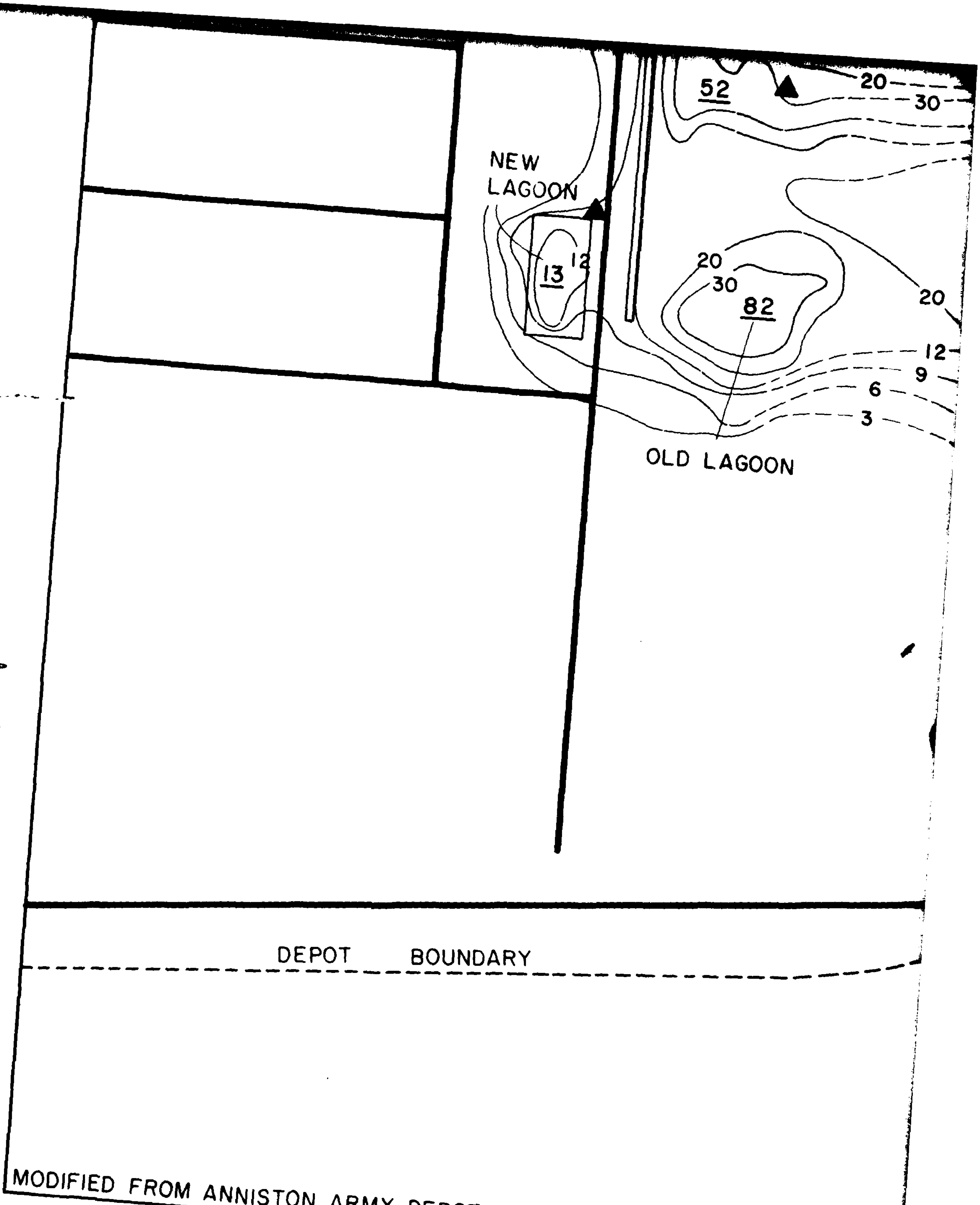

NEW
LAGOON
13
12



AGE CHANNELS
6
12
9
20
30
20
12
9
6
3
ON
DIVERSION
MAIN



(INSET SHOWING NORTHERN SINKHOLE AREA)



MODIFIED FROM ANNISTON ARMY DEPOT TOPOGRAPHIC MAP

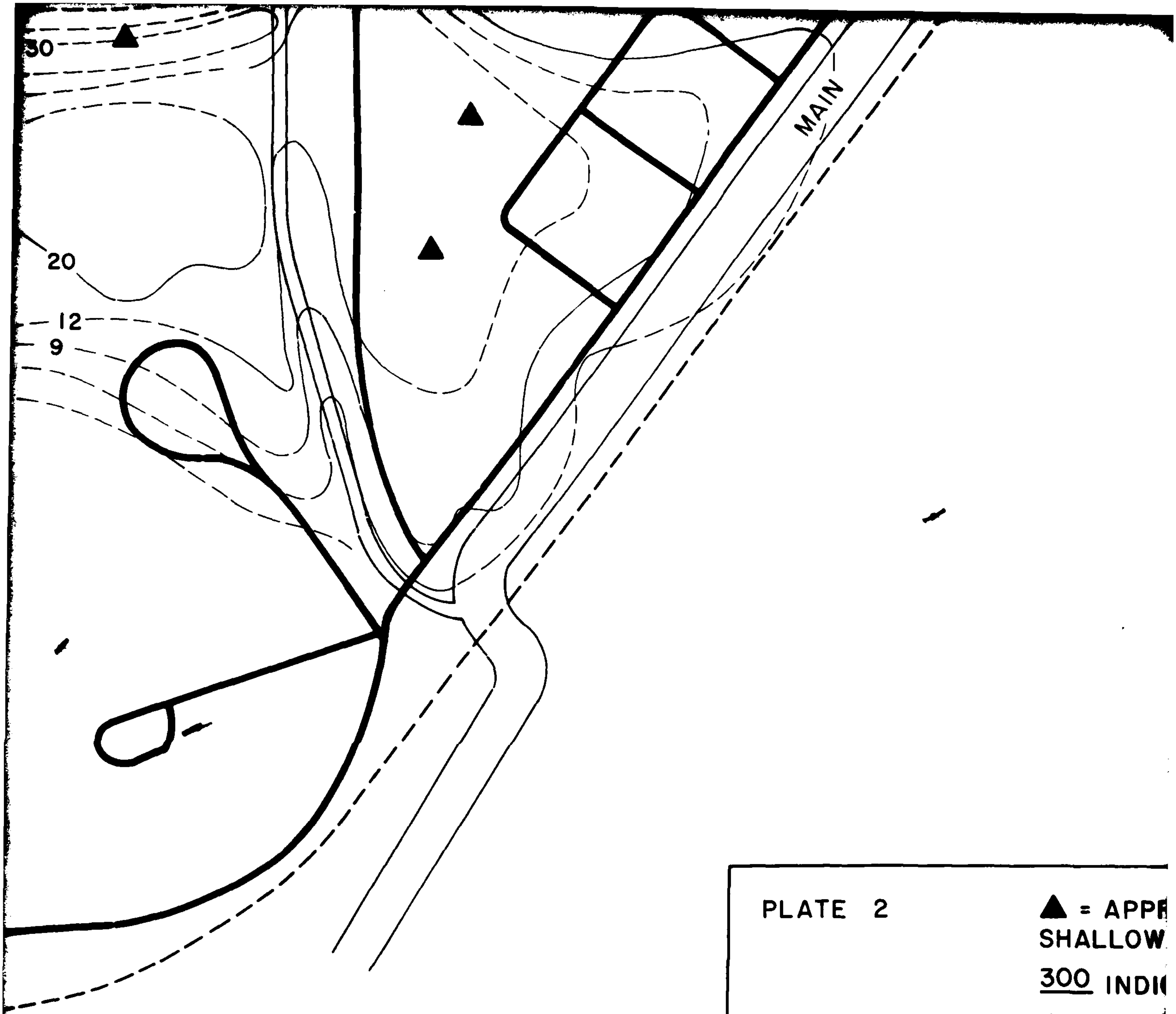


PLATE 2

▲ = APPR
SHALLOW

300 INDI
ELECTRO
DASHED
CONTOUR

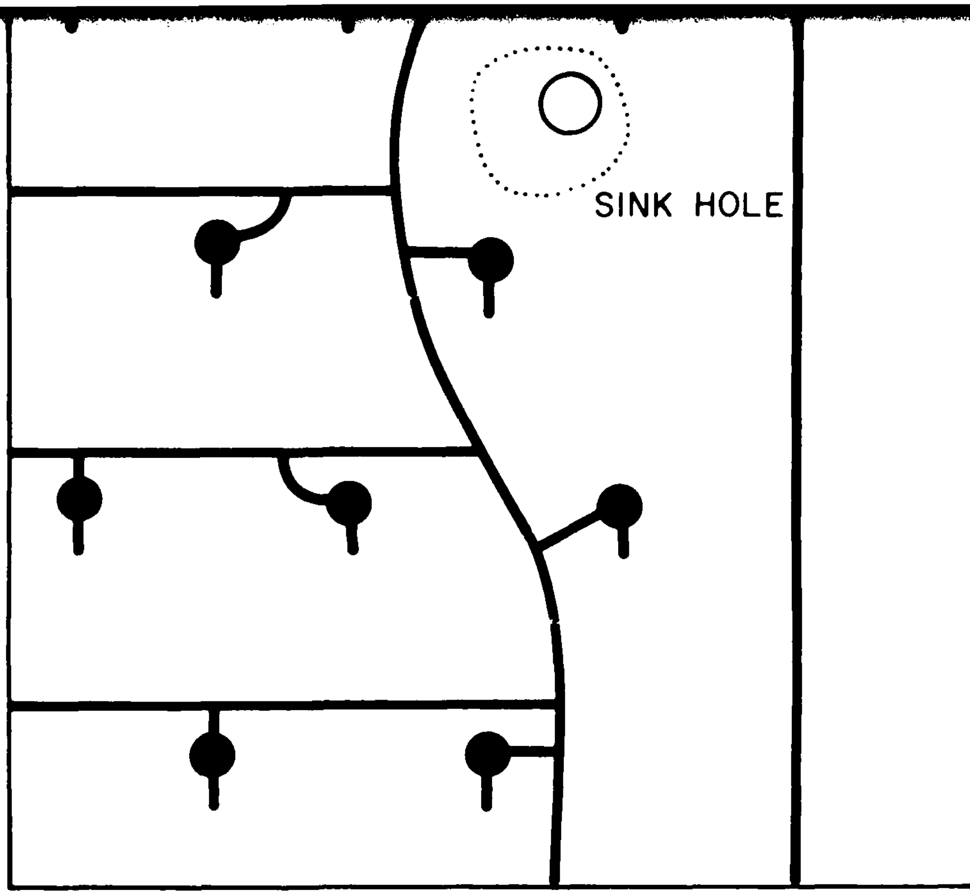
ANNISTON ARMY DE

SCALE 1" = 300'

ANNIST

1

8



(INSET SHOWING NORTHERN SINKHOLE AREA)

▲ = APPROXIMATE LOCATION OF RECOMMENDED SHALLOW WELLS

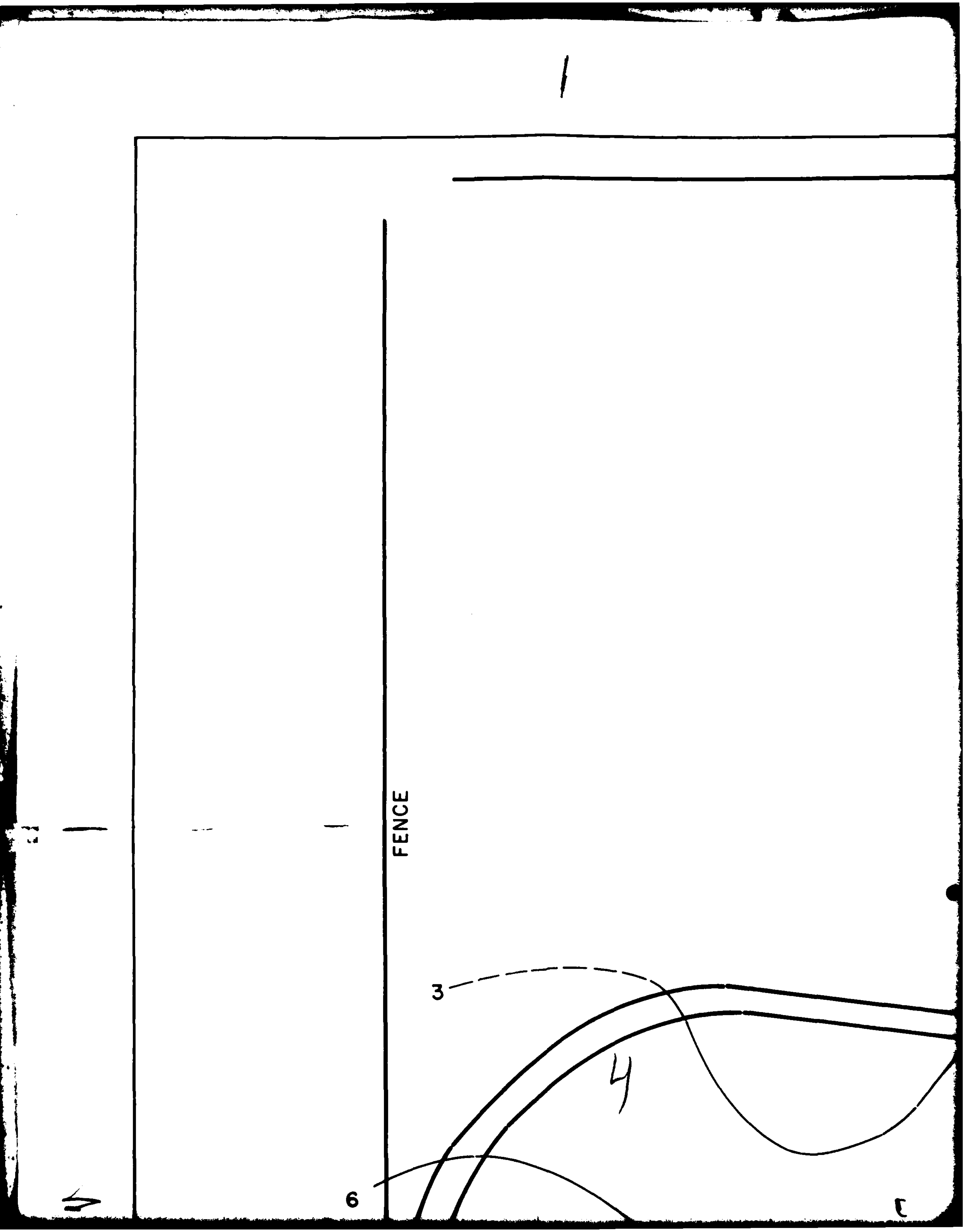
300 INDICATES HIGHEST RECORDED VALUE WITHIN CONTOUR

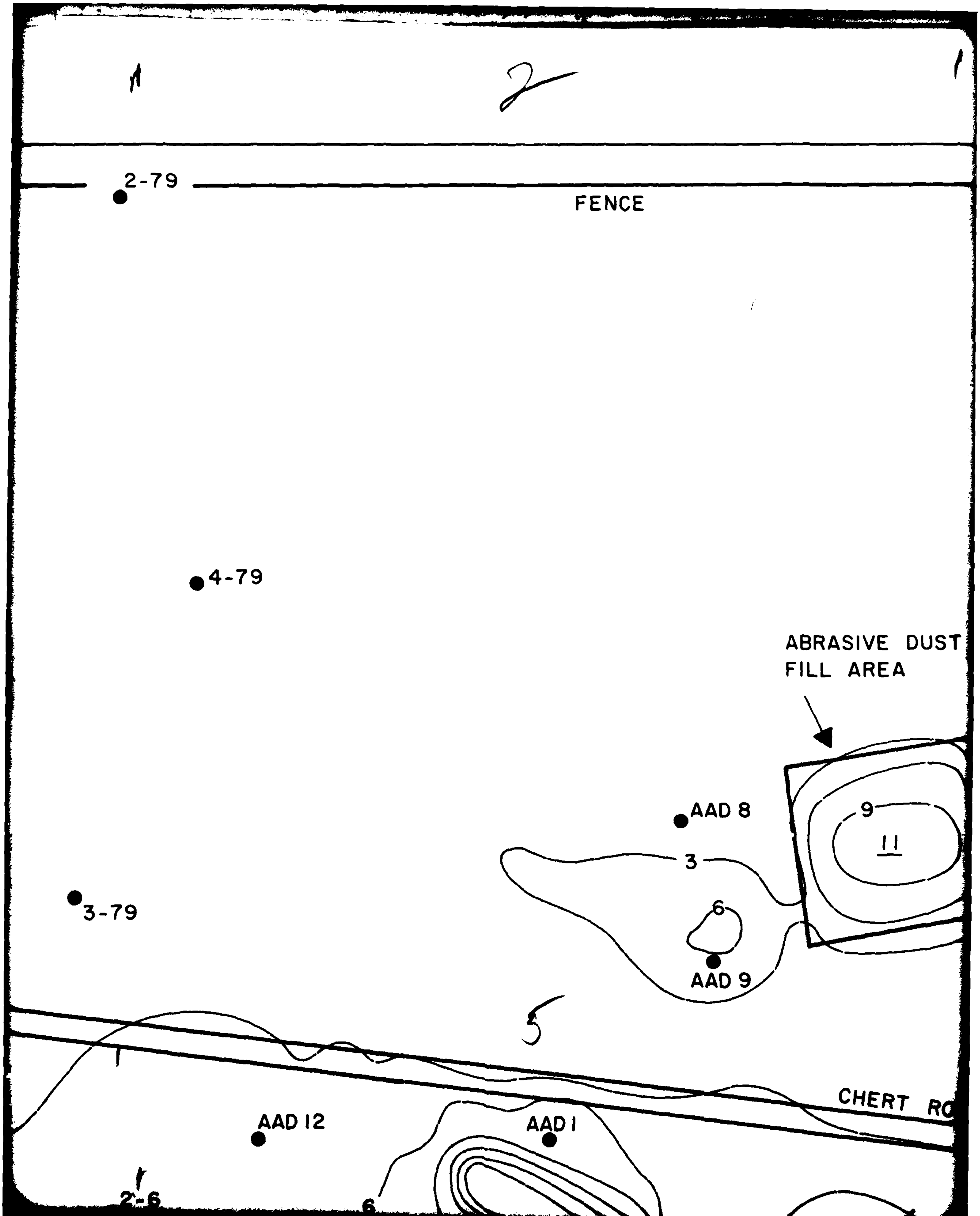
ELECTROMAGNETIC CONDUCTIVITY CONTOURS

DASHED WHERE INFERRED

CONTOURED VALUES REPRESENT MILLIMHOS / METER

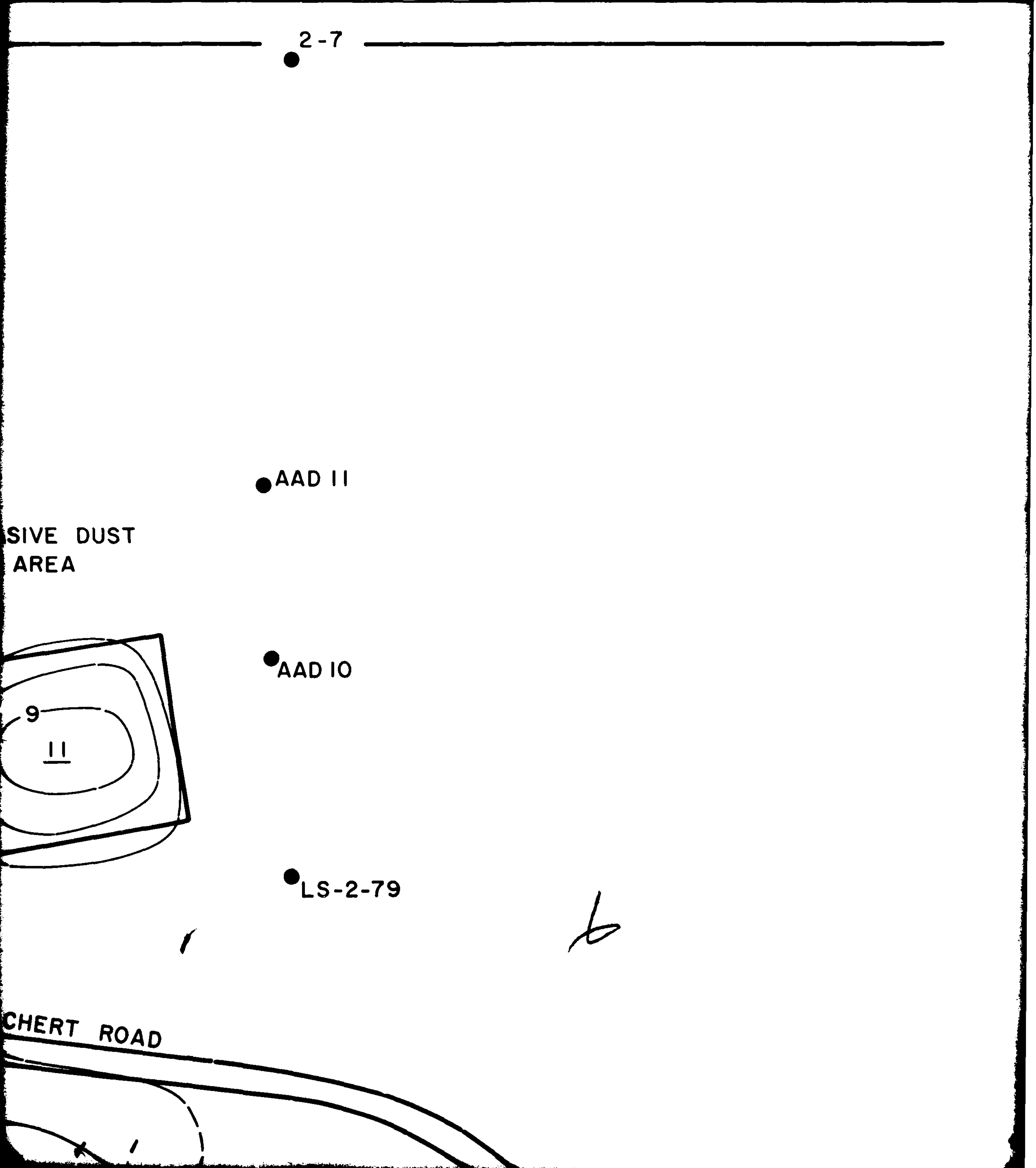
TON ARMY DEPOT	TECHNOS INC.
= 300' ANNISTON ALA	MIAMI FLA SEPTEMBER 1981

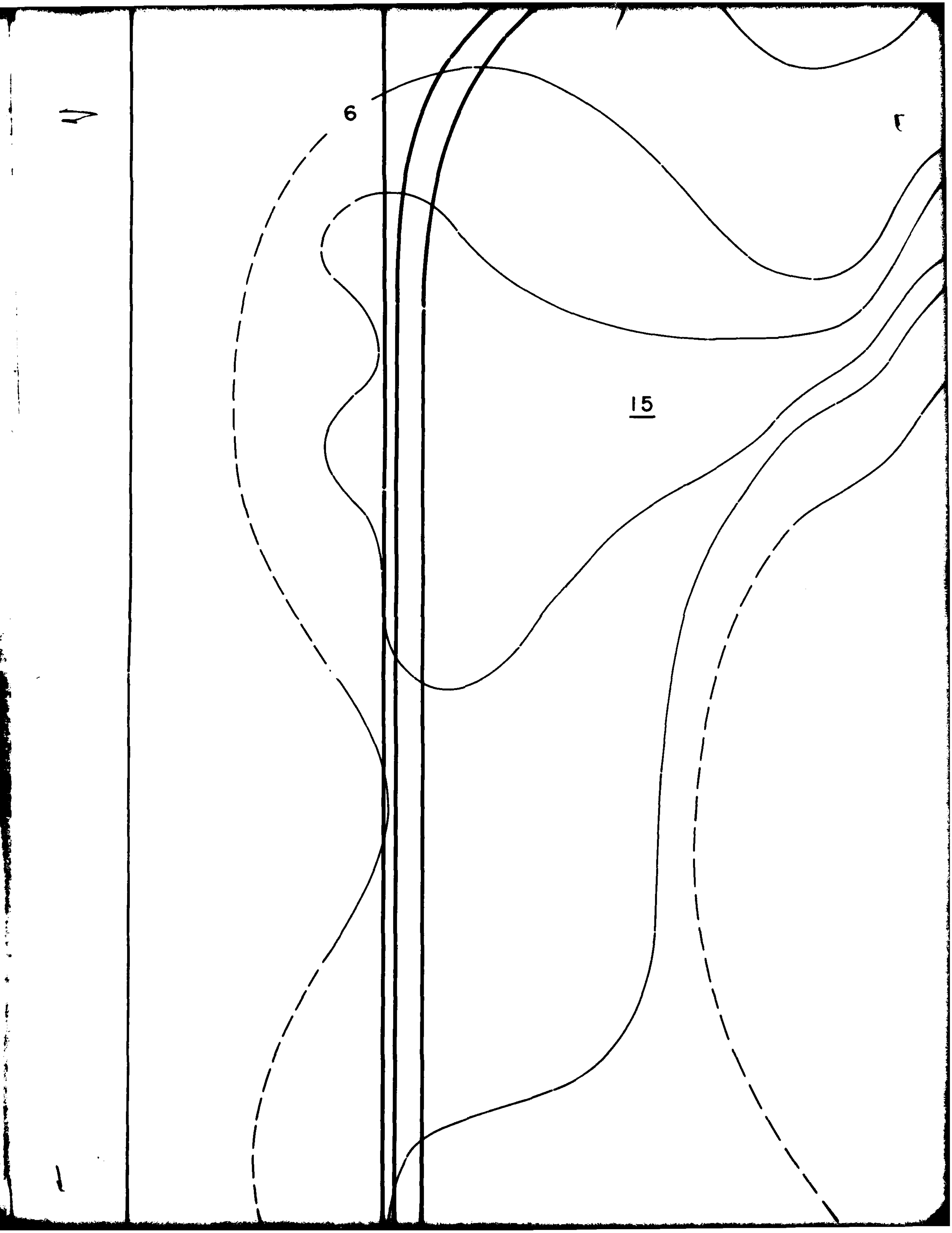

1
FENCE
3
4
6

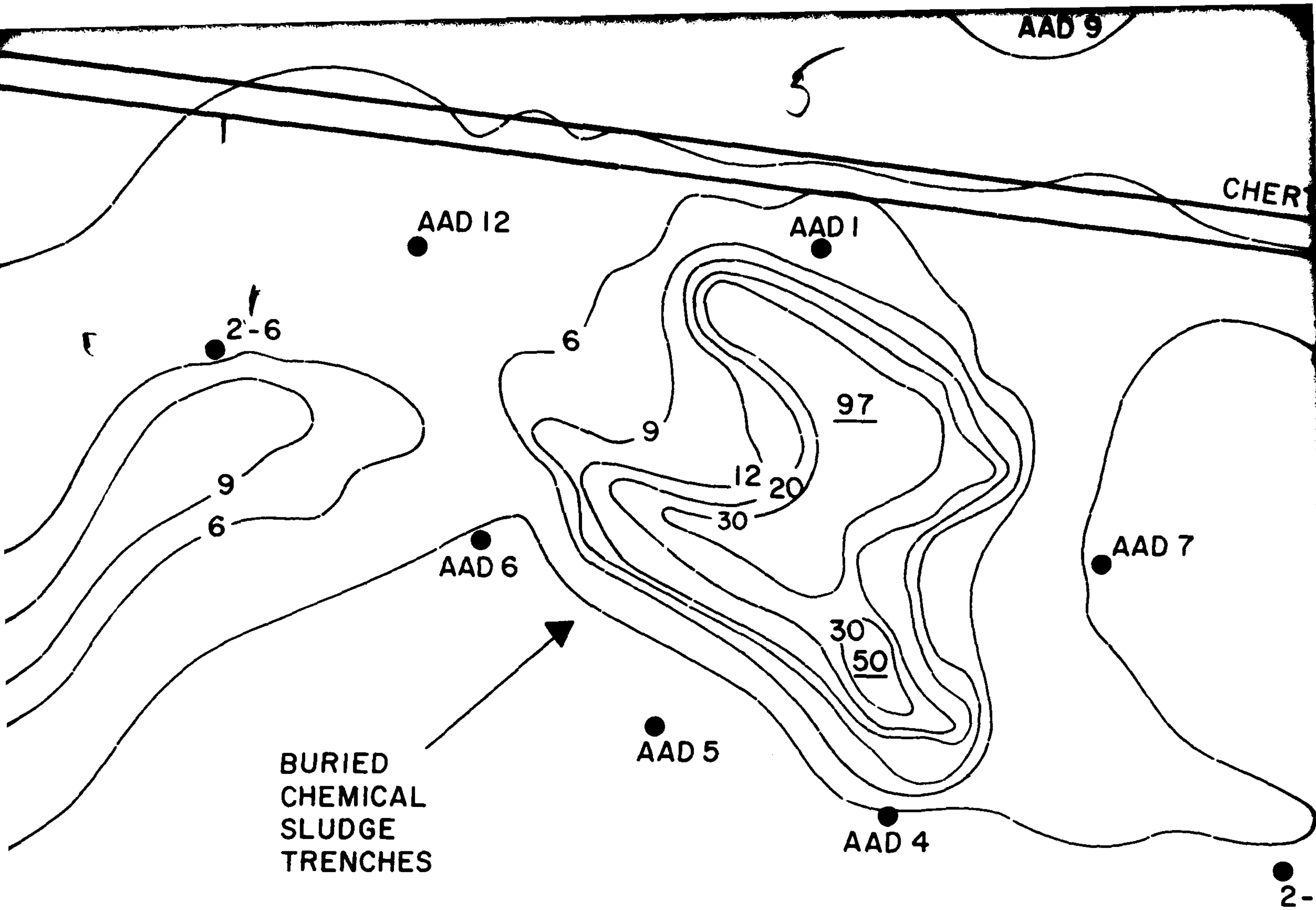


2-79
FENCE
4-79
ABRASIVE DUST
FILL AREA
AAD 8
9
11
3
3-79
6
AAD 9
CHERT RO
AAD 12
AAD 1
6

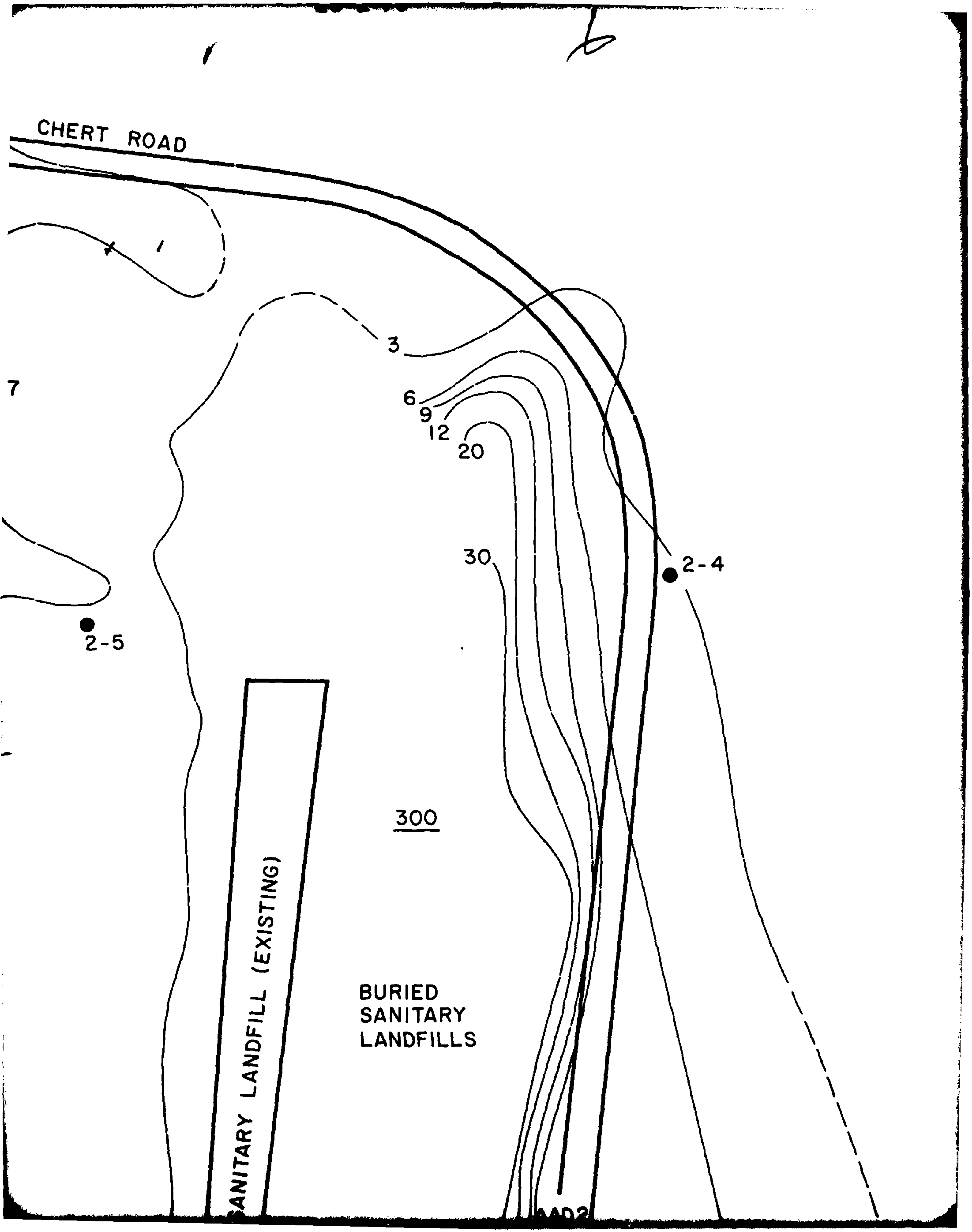
1 3 1



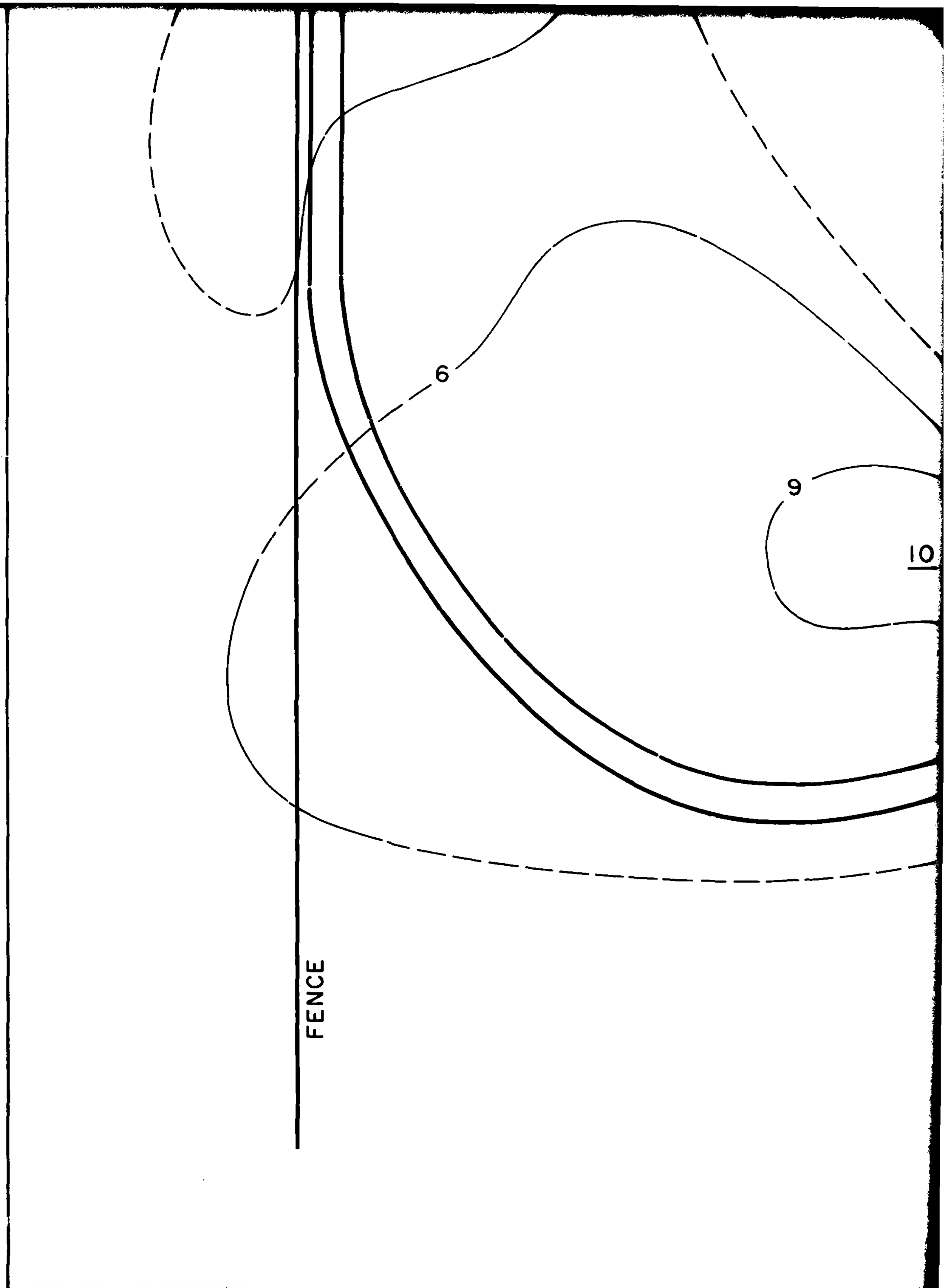

6
15



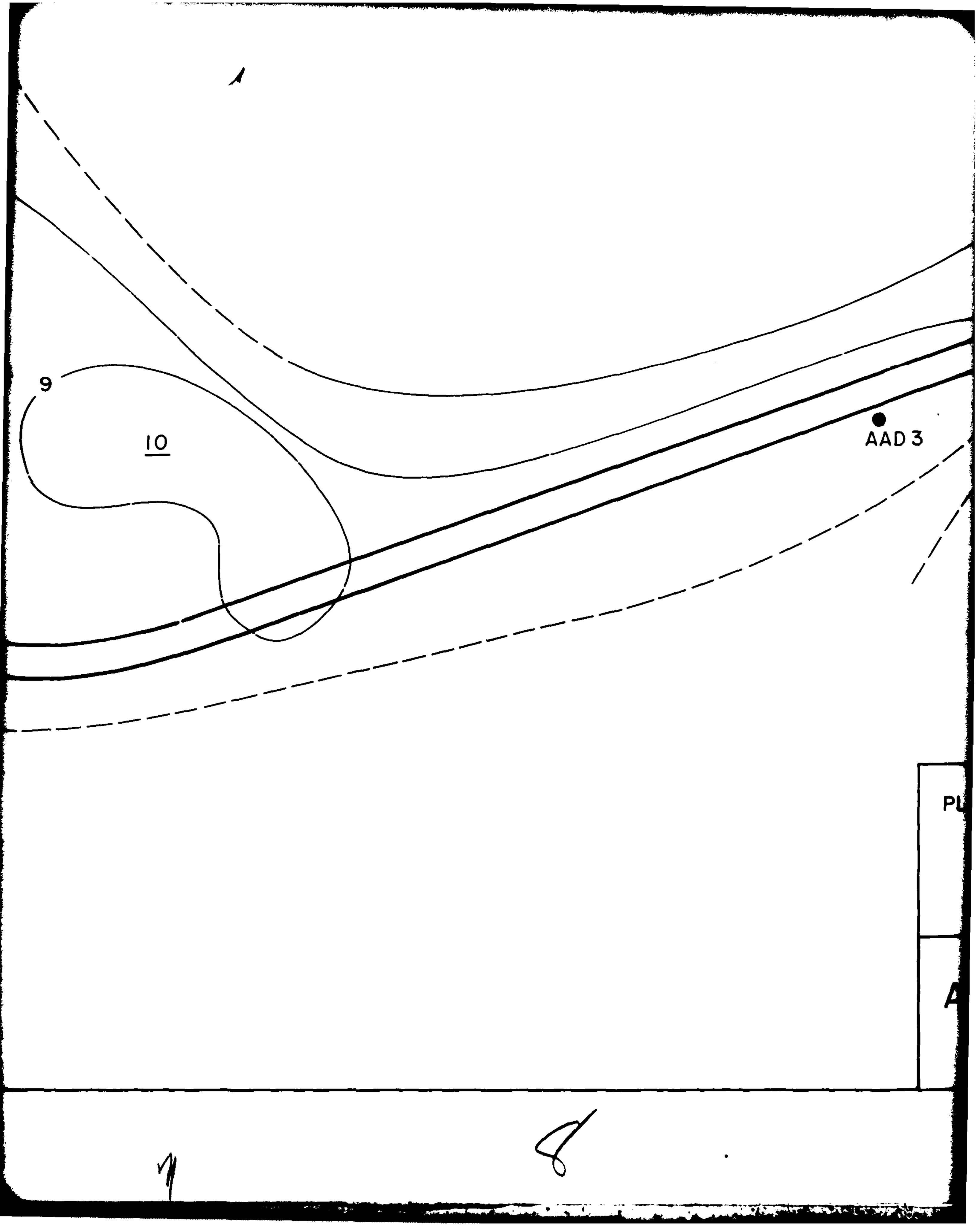
AAD 9
CHER
AAD 12
AAD 1
2-6
6
97
9
12
20
9
6
30
AAD 6
AAD 7
30
50
BURIED
CHEMICAL
SLUDGE
TRENCHES
AAD 5
AAD 4



CHERT ROAD
3
6
9
12
20
30
7
2-4
2-5
300
SANITARY LANDFILL (EXISTING)
BURIED
SANITARY
LANDFILLS



7


9
10
AAD 3
PL
A

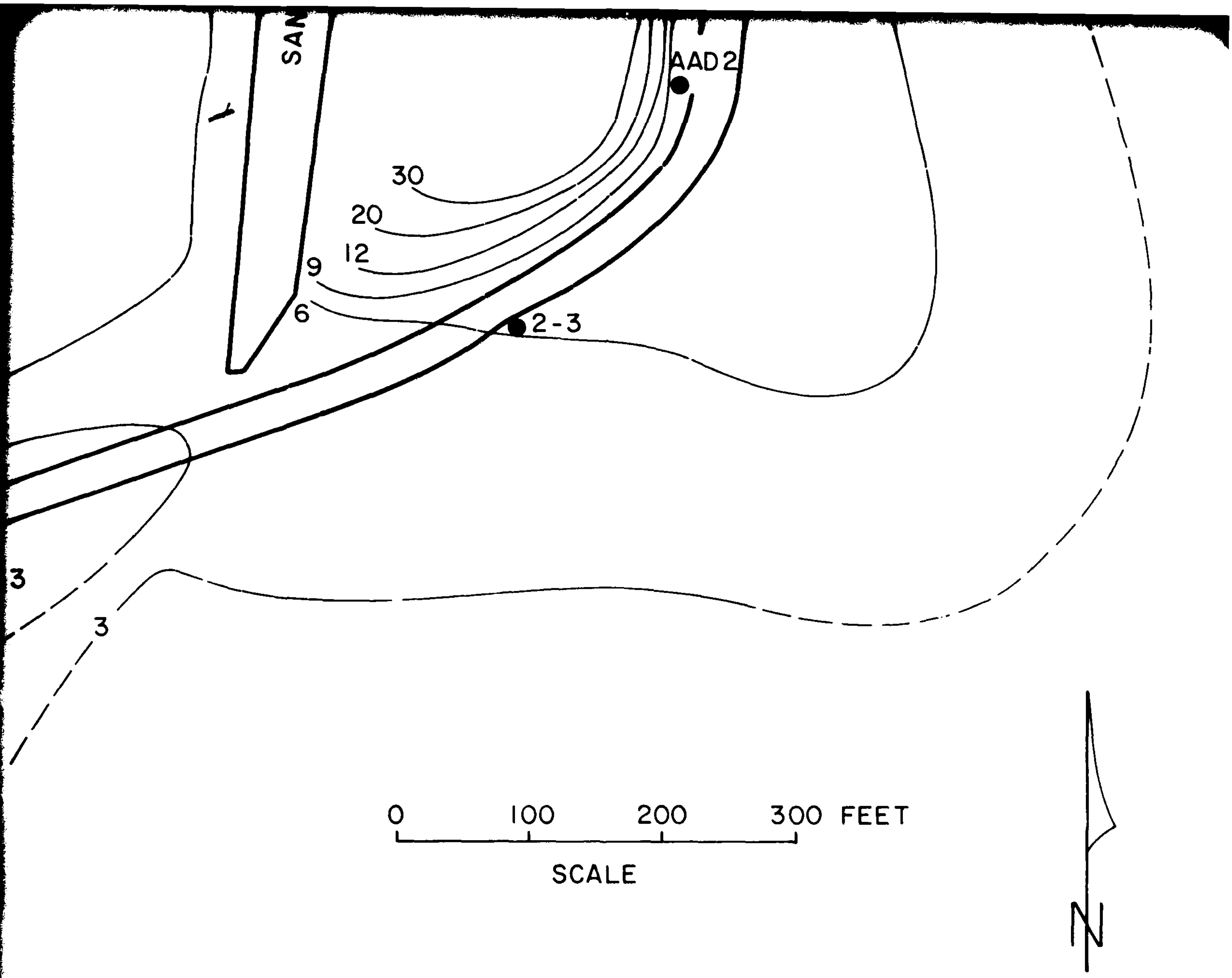


PLATE I

300 INDICATES HIGHEST RECORDED VALUE WITHIN CONTOUR
ELECTROMAGNETIC CONDUCTIVITY CONTOURS
DASHED WHERE INFERRED
CONTOUR VALUES REPRESENT MILLIMHOS / METER

ANNISTON ARMY DEPOT

ANNISTON ALA

TECHNOS INC

MIAMI FLA

SEPTEMBER 198

1

9

FILMED

8